Electromyographic Analysis of the Swim Start

Bilateral Comparison of the Front-weighted and Rear-weighted Track Start from the OMEGA OSB11 Starting Block

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Abstract: Previous swim start studies involving electromyography (EMG) consistently comprised unilateral measurements and the attachment of the swimmer via cables to a computer. Therefore the present work aims for an overall picture of the muscle activation pattern during the swim start by conducting bilateral measurements with minimal restriction of motion. On that account a multichannel surface EMG device with a wireless Bluetooth connection and videography is utilized in order to assess the nowadays most common start dive techniques of competitive swimming events - differently weighted track starts from the *OMEGA OSB11* starting block. The data analysis identified that the normalized muscle activation levels were higher during the front-weighted than during the rear-weighted start - probably caused by shorter block times and less contribution of the arms. Furthermore the onset of the muscle activation seems to be different in between start dive techniques, as for instance the muscles of the rear leg commence contracting earlier while the muscles of the front leg start later in the rear-weighted compared to front-weighted starts. It is highly likely that this originates in the position of the center of mass relative to the muscles. A general overview over the coordination of the different muscles could also be obtained: It became obvious that some muscles are the main drivers of the swim start (vastus lateralis, soleus) whereas others rather exerted supportive actions (gluteus maximus, semitendinosus, erector spinae longissimus).

1 INTRODUCTION

Fractions of a second often separate the winner from the rest in elite swim races. For instance, in 50 meter butterfly races the finishing times of the first and the third swimmer are only 0.09 s (male) and 0.05 s (female) apart (Commonwealth Games Delhi 2010, butterfly finals) (Slawson, 2012). Therefore each swimmer should try to improve every movement of the race. In short distance swimming events the start off the block is of special importance and may decide on success or defeat. General training techniques mainly include time measuring or perfunctory video analysis. Rule of thumb estimates widely serve as feedback base for the body position on the block. However, the fundamental unit which drives the body forward is often neglected - the muscle. Voluntary muscle contractions originate in the motor cortex. Thereafter motor neurons transport the necessary impulse to the muscle of interest and cause action potentials which travel along the muscle membrane. The amplitude and frequency of these action potentials can be measured by electrodes so that muscle activity levels and timing can be analyzed - this process is called electromyography (EMG) (Christensen, 1989). Maximal off-the block performance can be achieved if a beneficial muscle activation pattern is used as force production on the block and the orientation of the body segments relative to each other are determined by the activation of the activation of the involved muscles. Coaches and athletes should be able to analyze and react to certain - probably disadvantageous - activation patterns which can in return lead to better race times. Overall, this work is designed to gain an insight into the nowadays most common swim start techniques utilizing an electromyographic approach to investigate whether the principle of EMG and the available EMG technology can aid swimmers in improving their start dive technique.

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1.1 Previous Research on the Competitive Swim Start

The latest changes in the regulations of the Fédération Internationale de Natation (FINA Rules, FR 2.7) brought the company *Swiss Timing Inc.* to launch their new starting block *OMEGA OSB11* in April 2008 which is now predominantly used in international competitions (Murrell, 2012). On this block an additional foot rest (30% incline) is mounted to the back of the longer and steeper surface area allowing for an amended track start called kick start with better performance. Higher take-off velocities, shorter block times and faster times at different distances could be recorded (Honda et al., 2010; Biel et al., 2010; Ozeki et al., 2012). These facts brought the grab start to mostly vanish from elite swimming contests (Vint et al., 2009). Beyond that different studies discovered that moving the center of mass backwards during the track start is beneficial compared to the classical front-weighted track start (Welcher et al., 2008; Vilas-Boas et al., 2003). A recent study took these findings and observed the performance of a front-, neutral- and rear-weighted kick start from the *OMEGA OSB11* over a distance of 15 meters. The results indicated faster times at 15 meters for the neutral- and rear-weighted variant of the kick start from this new starting block (Barlow et al., 2014). Currently ongoing research takes further parameters into account including stance width, height of the center of mass and foot preferences of the swimmer (Kibele et al., 2015).

In 1964 surface EMG had its debut in the water environment and introduced a new variable to swimming movement analysis: muscle activity (Barthels, 2015). During the last decades Electromyography found its way into competitive swimming research. Fatigue analysis of different swim styles (Conceição et al., 2010; Yasushi Ikuta et al., 2012) and dry-land exercises (Ganter et al., 2007; Nazário-de-Rezende et al., 2012) form the majority of EMG papers in swimming. As most of the commercially available EMG systems are not waterproof and rather sensitive to rough under water movements, measurements have been restricted to plain swimming motions without regular starts and turns. Making matters worse, a large number of EMG systems has to be connected to a computer via a multitude of wires which may impair the natural motion of the swimmer.

The swim start move in particular was only subject to three scientific studies. A first paper observed electromyographic activity of two different variants of the backstroke start – feet immerged or feet emerged. Seven electrodes were placed unilaterally on arm, trunk and leg muscles (de Jesus et al., 2011). Another study also focused on the backstroke start in order to see how different the muscle activation pattern is in between subjects. Here eight electrodes were placed on the right side of the body (Hohmann et al., 2008). A third paper dealt with the biomechanics of the grab and track start technique and again eight electrodes were positioned on upper and lower extremities as well as the trunk on the right side of the body (Krueger et al., 2003). All these papers share the fact that the measurements were conducted unilaterally which does not allow an overall examination of the movement. Additionally all subjects were fixed via cables to the main acquisition unit. This may have affected the motion during the examined start technique.

1.2 Purpose of the Paper

Even though EMG measurements are sensitive to external influences - which especially applies to its use in the water environment - it has been decided to advance research regarding the muscular activity during the block phase of the swim start. It is assumed that this knowledge may help in optimizing start techniques as well as suggesting new training methods and exercises (Clarys et al., 1993). Besides this the relationship between EMG data and kinematic variables is said to play a key role in the evaluation of swimming performance (Conceição et al., 2013) and should therefore be investigated further.

2 METHODS

Bilateral measurements with minimal restriction of motion are to be achieved by carefully selecting the most important muscles of the swim start and employing a multichannel surface EMG device using Bluetooth technology to transfer the measured data to a computer. In a second step it is analyzed whether the EMG data can be linked to other variables of the swim start including angles from the block and instantaneous horizontal velocities (kinematic data). It is moreover assessed whether the results can be connected to the outcome of other related studies.

The focus is placed on the front- and rear-weighted kick start (Figure 1) as those techniques are the most widely applied ones off the *OMEGA OSB11* starting block and are subject to the latest swim start studies (Barlow et al., 2014; Kibele et al., 2015). Due to a limitation of time, equipment and staff the observations concentrates on the block phase instead of including flight and dive phase parameters. Moreover technology constrains an analysis of the total start sequence: Bluetooth transmission does not work under water. This choice is endorsed by the literature: All subsequent components of the swim start are influenced by the block phase what gives each swimmer the task to strive for maximal off-the-block performance (Mason et al., 2007).

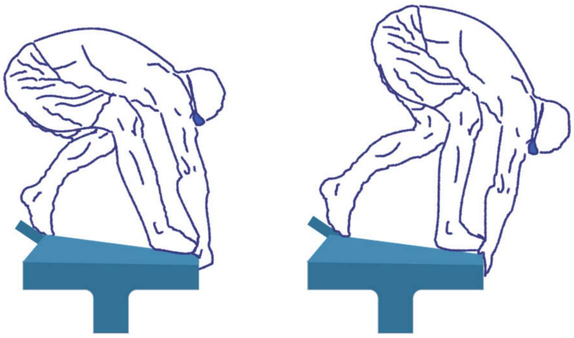

Figure 1: Rear-weighted (left) and front-weighted (right) initial start position on the block.

2.1 Participants

Three males and three females (five Swedes, one American) took part in this study. Table 1 shows the anonymized personal data of each swimmer. All swimmers were competing on developmental or national level. Four swimmers preferably had the right foot on the front edge of the starting block, two of them the left foot.

Table 1: Personal data of all participating subjects (Lat. = Laterality, Pref. Pos. = preferred weight distribution on the block).

No.	Gender	Age	cm/kg	Lat.	Pref. Pos.
S1	Male	19	179/75	right	Neutral
S2	Male	20	192/74	right	Front
S3	Female	20	173/65	right	Front
S4	Female	19	173/75	right	Front
S5	Male	22	177/79	right	Front
S6	female	22	171/61	right	Neutral

2.2 Equipment

The EMG device of choice is the telemetric unit *MQ16* by *Marq Medical* which weighs 120 g and has a data buffer memory of 60 MB that collects the data and a Bluetooth transmitter sends it to a computer. Preamplifiers amplify the signal close to the electrodes and conduct analog to digital conversion. The noise level of the *MQ16* is specified to be less than 3 μV (Meyland et al., 2014). The default sampling frequency is 1024 Hz which is sufficient for EMG signals ranging between 20 and 500 Hz. However, it was decided to set the sampling frequency of the *MQ16* to the widely used value of 2048 Hz (Ali et al., 2014; Barlett, 2007). Surface electrodes are applied in a bipolar configuration with a common ground and made of Ag/AgCl. As the device is to be used under wet conditions it has to be protected by a waterproof casing (*iPad®mini™case* by *ECase).* Transparent film dressing (*Tegaderm™, 3M™*) is chosen as covering for the electrodes and will be additionally fixed with foam tape (*Microfoam, 3M™*). Furthermore an accelerometer (mounted to the ankle of the rear foot) is used to track the swimmer's first motion on the block after the starting signal and a pressure mat is used to track the last motion on the block (foot-off moment). These two event markers are then used for time normalization of the movement for successive averaging of trials. The *Casio Exilim EX-FH25* video camera (shutter speed 1/500 s, 120 fps) is mounted to a rigid tripod to allow the recording of the swimmer in the sagittal plane. It was positioned perpendicular to the plane of motion approx. 5 m from the center of the swimming lane.

2.3 Measurement Protocol

Personal information of all subjects was captured and they signed a letter of agreement. Thereafter the electrode placement procedure commenced considering the SENIAM guidelines (Surface Electromyography for the Non-Invasive Assessment of Muscles, EU project) regarding the electrode location and positioning process. Nine muscles of the back and the lower limbs were chosen to represent the most relevant muscles during the start dive in swimming: erector spinae longissimus, gluteus maximus, vastus lateralis, semitendinosus and soleus. The skin area which was supposed to be covered by the electrodes was shaved, scrubbed with sand paper and then cleaned with an alcohol wipe. This was followed by attaching the *MQ16* to the waist of the swimmer and connecting the cables to the electrodes. Figure 2 shows that the electrodes including the pre-amplifiers were covered by waterproof tape with a size of at least 20 x 10 cm. All edges were additionally fixed by waterproof foam tape to prevent water induced detachment of the sealing. The accelerometer was mounted to the inside of the rear ankle and covered in the same manner as the electrodes.

Figure 2: Covering of the electrodes and placement of the accelerometer right above the rear ankle.

The movement of the swimmer was supposed to be as unrestricted as possible. Consequently it was decided to supply the swimmers with commercial tights to fix the cables to the lower limbs. This step had a beneficial secondary effect: minimization of cable motion. Figure 3 illustrates that pink markers with a diameter of approximately 4 cm were placed on the four landmarks defining the body segments: ankle, knee, hip and shoulder (Krueger et al., 2003).

Maximum voluntary contractions (MVC) performed on a gym bench are used to normalize the amplitude of the EMG signal. Normalization makes it possible to conduct an analysis which is not based on absolute values. Thereby comparisons between trials of the same subject or between different individuals can be made. Three maximal contractions against an insuperable resistance are performed for each muscle. A duration of six seconds and a short period of rest in between is chosen (Masso et al., 2010; Halaki et al., 2012). From different papers the most feasible MVC tasks for the muscles of interest in the present study were selected (Halaki et al., 2012; Konrad, 2005). For the reason that varying electrode placement might change the measured EMG signal, the MVC recordings for normalization were conducted with the same configuration as the subsequent EMG start dive measurements. As the wet pool environment might impair the electrode fixation, the MVC measurements were performed beforehand in a dry environment. Prior to executing the MVC tests, the swimmers gave feedback on their positioning and the static resistance they had to work against. Only if the positioning was suitable for the measurement and comfortable for the swimmer, the recording was started.

After all preparatory procedures were undertaken, the swimmer was ready to conduct three front-weighted and three rear-weighted start dives. Figure 3 sows subject S4 in a rear-weighted starting position. With respect to various existing start jump techniques the swimmers included a few additional start jumps of the requested techniques into their regular training during the previous weeks. In the front-weighted position they were asked to distribute the majority of their weight on the front foot whilst still preserving a stable stance on the block and in the rear-weighted position they were instructed to allocate the majority of their weight to the rear foot and at the same time maintain a stable position on the block.

Figure 3: Swimmer with fixated electrodes and markers and the *MQ16* on the back. OSB11 cover with pressure mat placed under the front foot.

The subjects were directed to propel themselves off the block with maximal effort like they would do in a competition. In order to prevent the waterproofing bag and the electrode sealing from damage, the swimmers were directed to not perform any powerful swim strokes but return to the edge of the pool by exerting cautious arm strokes. They were randomly asked to apply one or the other technique and after each trial they had approximately five minutes of rest. All trials were performed in the same way: When the Bluetooth connection between the *MQ16* and the computer was established and the swimmer was in readiness, the EMG recording was started. Right after that the *MQ16* transmit trigger (connected to pressure mat) was enabled. The camera operator then started the video recording, gave the prestart command "On your mark!" and then activated the start signal.

2.4 Data Analysis

As the swimmer's movement off the starting block only comprises a duration of around a second, it is assumed that the fatigue effect (frequency analysis) of the involved muscles can be neglected. Therefore the subsequent data analysis focused on the analysis of EMG amplitudes and the timing of the muscle activation of the different muscles relative to each other. The *MATLAB R2013b* software was utilized for this purpose.

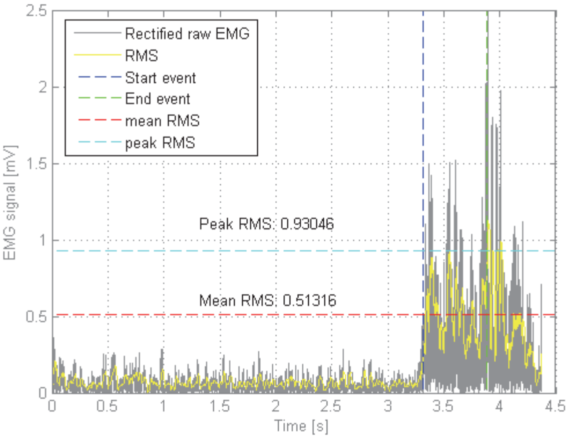

Figure 4: Processed signal (vastus lateralis rear, S3) with mean and peak RMS values and markers depicting the start and end of the block phase.

The processing steps included rectification of the signal, correction of a possible DC offset and determination of the linear envelope or root-mean-square (RMS) to specify EMG amplitude (Lamontagne, 2000). Figure 4 shows an example of an EMG amplitude analysis. Additionally on- and offset set times of muscular activity were calculated and the time stamps from the accelerometer and the pressure mat on the starting block were found.

The video data was predominantly processed with the software *Tracker* (*Tracker* software, version 4.8x) which helps in calculating times, angles and velocities after tracking the markers (Figure 5). Filtering of the digitized landmarks was again done in *MATLAB R2013b*. Differences in between the two start techniques were tested by means of paired t-tests using *SYSTAT 13*.

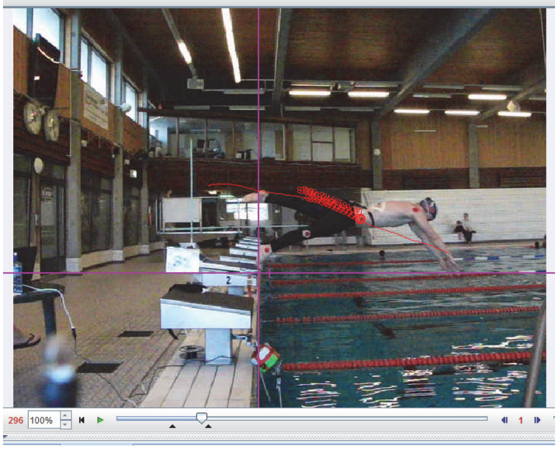

Figure 5: Video scaling & digitizing of the hip marker (approx. centre of mass) with the software *Tracker*.

3 RESULTS

Many start dive recordings were accompanied by intrusion of water under the electrode sealing, which resulted in erroneous data sets. An averaging of different trials of the same position and subject would then lead to unnaturally high or low voltage values, which do not reflect the actual activation. Therefore it was decided to neglect the time normalization and successive averaging of the three front-weighted and three rear-weighted recordings of each subject but select the best front-weighted and the best rear-weighted data set of each subject. For that reason only five front-weighted and six rear-weighted data sets enter the final data analysis.

As the subjects have been introduced to the concept of recording maximum voluntary contractions prior to the test day, meaningful MVC recordings were obtained. Additional time during the MVC tests to adjust the position on the gym bench or the fixation of the limbs, also contributed to the positive outcome of the MVC recordings. Contraction periods could clearly be separated from rest periods, which facilitated proper RMS calculations and identification of the maximal voltage value for each muscle.

However, as also depicted in other papers, MVC recordings may not be appropriate to normalize dynamic movements as they represent the ability of the muscle to contract in a static setting. In dynamic movements the synchronization of motor units is different. This constraint must be kept in mind.

3.1 Activation Levels

The main actors (vastus lateralis front/rear, soleus front/rear) predominantly register the highest activation levels, ranging between 48.6% and 191.0% for mean RMS. Additionally the standard error is rather high for these strong, rapidly acting muscles. The gluteus maximus rear and semitendinosus rear settle just below with an average activation of 38.1% and 34.1% respectively. The back muscles (erector spinae longissimus) as well as the gluteus maximus front and semitendinosus front show lower mean RMS values 18.9% and 29.4% with smaller standard errors than the main actors.

3.2 Activation Timing

After the reaction time has passed the muscles begin to take up their work at different times. It can clearly be seen that the erector spinae longissimus is on average active before any motion can be detected (accelerometer/video). Almost synchronously the gluteus maximus and semitendinosus of the rear leg take up their work and also the semitendinosus front begins contracting almost simultaneously with the two aforementioned muscles. Shortly after the vastus lateralis rear and soleus rear show their activation onset. Figure 6 illustrates that, after almost half of the block time has passed, the gluteus maximus front comes into the game marking the start of the pushing phase of the front leg. Lastly the S front and the vastus lateralis front perform the last powerful action off the block with an onset at 54.8% and 57.1% of total block time respectively.

Generally the rear leg comes into action before the front leg. When observing the two different initial positions it can be seen that the muscles of the rear leg during the rear-weighted start generally start contraction earlier than in front-weighted starts. On the other hand, the muscles of the front leg seem to have a later onset during the rear-weighted than during the front-weighted start.

3.3 Kinematic Parameters

Reaction times (start signal until start of motion) of 0.245 ± 0.013 s have been identified by means of *Tracker* from the video recordings. It can be seen that the reaction times for the rear-weighted start are often shorter (0.236 s) compared to the front-weighted start (0.254 s). Beyond that it was observed that the swimmers remained on average 0.074 s longer on the starting block in rear-weighted track starts.

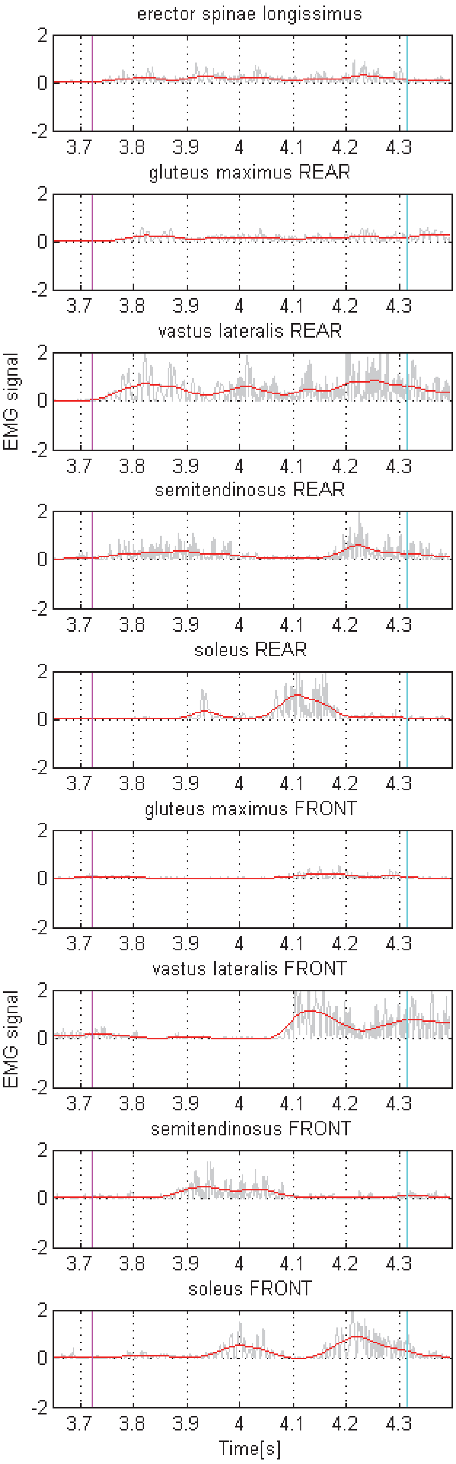

Figure 6: EMG signals [V] of all nine investigated muscles during a front-weighted start dive (S1). The pink line depicts the start of motion (accelerometer signal) and the blue line represents the foot-off moment (pressure mat signal).

This leads to a longer average start-to-flight time (start signal until foot-off) for the rear-weighted start (0.841 ± 0.034 s) off the *OMEGA OSB11* starting block - even though the detected reaction times were shorter than for the front-weighted starts. For a front-weighted start the swimmers required on average 0.783 ± 0.045 s. Generally the men achieved faster starting times than the women.

The calculated angles from the block for the six subjects depict a certain pattern with regard to the initial position on the block: rear-weighted starts seem to lead to smaller angles. Yet it cannot be proven that the angles during the front-weighted start are significantly higher than during the rear-weighted start dive (p-value = 0.097). Most angles measured per subject per position are close together, but the angle from the block ranges largely in between subjects depicting values ranging from 25.1 to 48.6 degrees.

The instantaneous, horizontal velocities also indicate a particular pattern: the velocities off the block are significantly higher for rear-weighted starts (p-value = 0.013). The angle also seems to have a certain influence on the velocity as it is frequently detected that the smaller the angle, the higher the horizontal velocity at foot-off becomes. An average instantaneous, horizontal velocity of 2.166 ± 0.112 s is found for front-weighted and 2.369 ± 0.110 s for rear-weighted starts. The velocity recorded might however not represent the maximal velocity throughout the jump. For different subjects higher horizontal velocities were found shortly before or after foot-off, depending on the individual stretching pattern during this phase of the start.

4 DISCUSSION

The EMG data acquisition during the start dive formed the core of the present investigation. Each subject conducted three front-weighted and three-rear weighted kick starts off the *OMEGA OSB11* starting block. As favored the subjects did not report any impairment of motion due to the cables on their limbs or the *MQ16* on their back. When the electrodes remained dry under the waterproof tape, they were able to measure the muscular activation during the start dive. This leads to the assumption that the selected electrode positions as well as the skin preparation chosen, were appropriate for the current study. The noise of the components has been found to be negligible and a certain variability in the data due to variations in between subjects has to be accepted. However, certain events negatively influenced the EMG data acquisition in the water environment – detachment of the electrodes from the skin and disturbance of clamps and amplifiers by the water.

It was found that the mean EMG amplitude during the rear-weighted start is significantly smaller than the amplitude during the front-weighted start technique. This is mainly caused by longer block times in rear-weighted starts as the center of mass (CoM) needs to travel a longer distance until foot-off than in the front-weighted version. Additionally the arms are capable of contributing a large part to the forward motion by pulling the swimmer out of the initial rearward position. The standard error was found to be much higher for the forceful main actors of the start dive (vastus lateralis, soleus) than for the other muscles. This may originate from the dynamics of the start dive leading to high voltage peaks in the EMG curve of these strong muscles.

A comparison of the onset times for front-weighted and rear-weighted start dives predominantly revealed an earlier muscle onset within the rear leg in rear-weighted starts. Certain muscles of the front leg, however, start contracting later than in front-weighted starts. This discrepancy leads to a non-significant difference between the muscular onset of the front-weighted and rear-weighted track start technique when conducting a statistical analysis. A reason for this might be that the initial position places a high weight on the rear foot allowing an immediate force production in the beginning whereas the CoM has to be moved a long distance before the muscles of the front leg can start executing their function.

The parameters obtained from the video recordings support the assumption that the selected subjects are suitable representatives for aspiring swimming professionals. When opposed to the outcome of other swim start studies, the subjects of this study show similar results - however, not with the same magnitude as elite swimmers (Barlow et al., 2014).

Visually connecting the EMG measurements to the video recordings ultimately revealed the motion sequences during which the different muscles are predominantly active (Figure 7). The interplay of different muscle groups was identified, for instance the almost simultaneous activation of the gluteus maximus and the vastus lateralis muscles and the dissimilar activation of semitendinosus and soleus in the same leg. The collaboration of the gluteus maximus and the vastus lateralis was also identified previously (de Jesus et al., 2011).

Initial position on the block

Onset: ESL, GM rear, VL rear, ST rear, S rear and ST front

Onset: GM front, VL front and S front

All muscles contribute their part to the start dive

Figure 7: Images of a rear-weighted start dive (S4) indicating the different onset times of the recorded muscles.

The mentioned dissimilar activation of Hamstring and Calf muscles can be explained by the differing required performance conditions. During the start dive the Hamstrings influence the swimmer's hip and knee extension at smaller knee angles whereas the Calves seem to take up their work at larger knee angles conducting the last powerful movement on the block.

Besides, the semitendinosus of the front leg counterbalances the forces which are generated when the soleus of the rear leg pushes off the foot rest on the back of the block in order to preserve a secure stance on the block. After a leg has left the block the semitendinosus of the same leg might show another peak related to the injury prevention mechanism of the knee joint; At that point in time the soleus of that leg already shows strongly decreasing activation levels.

Moreover the back muscles as well as the gluteus maximus help in extending the swimmer into the favored streamline position as they show activation at the beginning of motion and right before and after foot-off. This role is confirmed by different swim start publications which assigned the same responsibilities to the abovementioned muscles (de Jesus et al, 2011, Hohmann et al., 2008). As the upward rotation of the trunk commences first with the help of the back muscles and leg extensors causing vertical acceleration of the trunk and simultaneously a force pointing downwards in the direction of the lower limbs, the extension of the legs only starts when the hips begin to be unweighted. A possible drop of activity in the hip extensors (gluteal muscles and Hamstrings) after the first part of the push phase might be related to the termination of the upward rotation of the trunk. Furthermore the fact that the muscular activation of the ST of the front leg peaks later than the one of the rear leg seems to be linked to the positioning of the muscle relative to the CoM meaning that the muscle in the front leg cannot contribute its part to the hip extension and stance stabilization until the CoM reached a certain location further to the front of the starting block.

After foot-off the muscle activation profiles vary remarkably in between subjects as each swimmer conducts different corrective and stabilizing movements during the flight phase (Hohmann et al., 2008). Some swimmers still show elevated EMG profiles in their back muscles whereas others continue to contract their soleus muscles for a beneficial feet position. It was neither aimed nor possible to make statements about later swim start phases as it is a highly individual issue and the Bluetooth connection vanishes upon water entry.

Taking the EMG recordings and the video data into account one might see that the rear leg is the initiator and main driver of the observed track start technique. It sets the body in motion and moves the CoM to the front of the starting block. Changing the initial position changes the activation levels and timing in both legs but the rear leg generally performs the bigger part of the work which can be seen in predominantly higher activation levels. However, without the stabilizing actions of the front leg, which form the basis for a solid stand on the block, and the last push off the block, which defines the positioning of the swimmer in the air, the start jump would not be as effective and efficient as it is.

5 CONCLUSION

Muscles vary largely in volume and structure leading to a different base of operation for each muscle and restricting the comparability of activation levels and timing in different muscles. Moreover some of the leg muscles observed belong to the group of biarticular muscles (e.g. gluteus maximus, Hamstrings) meaning that they traverse two joints and thereby have another principle of operation than monoarticular muscles (Bobbert et al., 1988). Additionally it has to be noted, that in complex movements like the swim start which include all body segments, muscles influence the joints they cross as well as other joints (Bobbert et al., 1988). Another issue is the link between EMG activation and produced tension: After a muscle has been stimulated, a delay of 20 to 100 ms occurs between a recorded muscular activity onset and the resulting mechanical output which can be observed in video recordings (Bartlett, 2007; Bobbert et al., 1988).

The complexity of the human body as well as the ambiguous relationship between EMG and kinematic data unfortunately limit the information one can extract from EMG measurements and a combination of those with video data. Solely activity levels and timing can be detected, but not the muscle's exact task within a movement (Bartlett, 2007). In order to avoid speculative interpretation, the present work did not assign a particular muscle to a certain function, body position or joint angle but gave a suggestion regarding the contribution of a muscle to a certain motion sequence during the swim start.

The physiological and mechanical considerations made within the scope of this work are not the only ones influencing the muscular activation during the start jump in swimming. In future investigations further muscles or muscle properties should be addressed and the location of the CoM or different body segments varied (Bobbert et al., 2007). Besides altering the scope of the investigation, improvements should be made regarding the equipment, for instance using wireless electrodes in order to facilitate better sealing, finding a solution for the Bluetooth loss between air and water and strengthening the synchronization of all applied measurement devices. Additionally trying to supply the swimmers and coaches with quickly processed, meaningful data would be a desirable advancement (Hamill, 2010).

It is assumed that a step in the right direction was made by pointing out the importance of the understanding of the muscular tasks exerted by the swimmers body. This can aid in developing training methods and prospective start dive techniques. Unfortunately the process of recording EMG with the current technology is highly sensitive and protracted so that an application in everyday swim training sessions is - for the time being - not feasible.

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