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ORIGINAL ARTICLE

BIOMECHANICAL ANALYSIS OF THE BACKSTROKE START TECHNIQUE IN SWIMMING

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This study researched in depth a 6-phase model that describes the kinematic and kinetic parameters of the backstroke start in combination with the time pattern and activity level of the muscles while executing the start movement. Nine male backstroke sprinters performed four backstroke starts over a distance of 7.5 m. During the start the overall start time, reaction time, wall time, flight time, and glide time were recorded. Kinetic data were measured as 3-dimensional ground reaction forces. The correlation ($N = 9$) of the resultant take off force and the final overall start time (7.5 m) turned out to be significant ($r\,[9] = -.82$, $p = .006$). Correlations were found between the times of hands off and take off ($r\,[9] = .70$, $p = .04$) and hands off and hip entry ($r\,[9] = .92$, $p < .001$). The influence of the kinematic and kinetic parameters of the above water phase (wall and flight activity) of the backstroke start technique is clearly shown by the analysis.

EMG-data were recorded for five of the nine backstroke sprinters by a water protected 8-channel EMG from eight arm, shoulder, trunk and leg muscles. To compare the quality of muscular activity patterns, the IDANCO-system served as an adequate method. The EMG recordings in the 5 swimmers indicated a medium repetition consistency and reproducibility of the identified patterns of muscle activity. In the initial hang phase, and the final glide phase the EMG recordings of the first dolphin kick demonstrated an identical and analogue movement behavior. During the flight phase, and especially during the water entry, the number of different muscle activation patterns grew significantly.

Keywords: swimming, backstroke start, 6-phase model, kinematic data, electromyography

Introduction

Cossor and Mason (2001) showed that the underwater speed during the glide phase of the start had a significant influence on the position within the starter field, and also on the total race time in the 100 m backstroke event. In addition, Graumnitz & Küchler (2007) concluded from their analysis conducted during the Swimming World Championships 2007 in Melbourne that at least in the women's races the above water phase is a key factor in the sprint performance in backstroke swimming. Thus, this study is based on a complex 6-phase model of the swim start (Krueger, Kirsten, Hohmann & Wick, 2006) and aims at the identification of kinematic and kinetic parameters that are relevant for the start performance in backstroke swimming. The kinematic and kinetic parameters are investigated in combination with the time pattern and the activity level of the muscles that generate and transmit the forces and fix the body (Hohmann, Fehr, Kirsten & Krueger, 2006), while executing the different movements during the backstroke start.

Former EMG studies of grab start and especially track start movements of elite female crawl sprinters revealed that the technical execution of the start technique and the muscle activity patterns show great interindividual variations during the above water and the underwater phase (e.g. Krueger, Wick, Hohmann, El-Bahrawi & Koth, 2003). As the technical execution of the backstroke start out of the water appears to be much more constant, it is hypothesized that in international level backstroke sprinters the EMG patterns of the most important propulsion and stabilization muscles are almost identical within and among the different athletes.

Methods

Subjects

Nine male backstroke sprinters, all members of the German national junior and senior teams in swimming, took part in the study. The elite swimmers ($N = 9$) had an average body mass of $M = 78.6$ kg ($SD = 7.1$ kg) and an average height of $M = 188.0$ cm ($SD = 5.0$ cm). The average age of the swimmers was $M = 21.5$ yrs ($SD = 3.7$ yrs), and their personal best time in the 50 m backstroke sprint was $M = 26.31$ s ($SD = 1.26$ s).

Kinematic measurements and instrumentation

Each participant performed four trials of the backstroke start over a distance of 7.5 m. The 7.5 m distance parameter is widely used in start investigations (e.g. Kibele, Siekmann, Fischer &

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Ungerechts, 2007) because it reflects primarily the quality of the start activities on the block, during the flight and water entry until the transition into the glide phase, and is not so much influenced by swimming actions below or at the water surface. Furthermore, this comparably short distance can be covered by one high speed camera, and it allows to use a comfortable length of the cable of the EMG measuring device.

The overall start time was recorded by high speed video analysis (Redlake Inc., 125 Hz), and split into reaction time (signal until hands off), wall time (signal until take off), flight time (take off until hip entry), and glide time (hip entry until head passing 7.5 m). The start signal was aligned with the video data by a flash light signal. The start section of the swimming pool was calibrated and a 2-dimensional video movement analysis was carried out to determine the kinematic parameters of the four start trials (see Figure 1). Kinematic parameters (split and overall start times, wall time (signal until take off), flight time (take off until hip entry), and glide time (hip entry until head passing 7.5 m), take off velocity) were calculated by motion analysis software (SIMI-Motion, SIMI Inc., Ger).

Dynamometric measurements and instrumentation

Kinetic data were measured as 3-dimensional ground reaction forces at a sampling frequency of 1.000 Hz by a mobile water proof force plate (Kistler Inc., Ger) mounted to the pool wall. Kinetic variables selected for further investigation were the resultant peak force at the time of hands off (F_{RMax1}) and the resultant peak force just before the time of take off (F_{RMax2}).

All interrelations and differences in the kinematic and kinetic data between the starts were tested by the Pearson correlation test, and by a paired t-test (SPSS; Version 12.0), respectively. Significance level was set by $p < .05$.

Electromyographic measurements and instrumentation

EMG provides information about muscle activation and the specific temporal pattern of the coordinative interplay between the propulsive and stabilizing muscles. In the present study, surface electromyography was used, which is more appropriate to global studies with athletes and better accepted by subjects than measuring with needle or fine wire electrodes (Rouard, Quezel & Billat, 1992). The skin was shaved, rubbed and cleaned, and the electrodes were fixed with adhesive tapes and plastic films (Tegaderm, 3M Inc.). EMG-data were recorded by a water protected 8-channel EMG (Biovision Inc., Ger) from eight arm, shoulder, trunk and leg muscles, located on the right side of the swimmers body (see table 1). The sensor location, the orientation of the electrodes and the inter electrode distance was chosen as recommended by the European SENIAM-Project in detail for each muscle (Hermens & Freriks, 1999). The chosen muscles represent the most important muscles for stabilizing the initial hang phase, the take off, flight and water entry movement and also the undulating whole body movement when executing the dolphin kicks during the underwater phase. It is assumed that the investigated muscles produce most of the explosive power needed for an effective start of the swimmer.

Raw EMGs were corrected to obtain the full wave rectified signals. The data were filtered by Butterworth at 10.0 - 400.0 Hz, 2nd-order according to the widely accepted recommendations given by the SENIAM Project (Hermens & Freriks, 1999), and averaged by Butterworth at 8.0 Hz, 2nd-order to get the envelope of the signal, which is particularly suitable for the following qualitative comparison. The amplitude of the linear envelope was then normalized with respect to the maximum muscle activity during the whole start movement up to the 7.5 m limit. Each muscle of each subject was used as its own reference (Rouard et al., 1992).

The time durations of the four phases of the *above water phase* (*reaction phase* from signal to the first movement, *pressure phase* from first movement to hands off, *jump phase* from hands off to feet off, *flight phase* from feet off to hip entry) and of the first two phases of the *underwater phase* (*entry phase* from hip entry to the first maximum depth of the feet and *glide phase I* with the first dolphin kick from first to second maximum depth of the feet) were normalized separately. The time and amplitude normalization allows for intraindividual

Figure 1. Above and under water view of the backstroke start movement.

Table 1

The eight muscles of the right side of the body chosen for the EMG in the backstroke start.

Upper body	**Lower body**
- m. deltoideus	- m. rectus femoris
- m. biceps brachii	- m. gluteus maximus
- m. triceps brachii	- m. semitendinosus
- m. erector spinae	- m. gastrocnemius medialis

and interindividual comparisons of the patterns of the muscle activities during the different movements of the backstroke start.

For the qualitative comparison of the muscle activity patterns, Bollens and Clarys (1984; see also Bollens, Annemans, Vaes & Clarys, 1988; Clarys, Toussaint, Bollens, Vaes, Huijing, de Groot, Hollander, de Witte & Cabri, 1988, Clarys, de Witte, Toussaint, de Groot, Huijing & Hollander (1988), Clarys, Publie & Zinzen (1994)) developed the IDANCO-system. The term IDANCO stands for *IDentical*, *ANalogue*, *COnform*, and *different* muscle activity patterns (see figure 2). The methodology of the IDANCO-system is based on the *qualitative judgements* of a scientific expert, who has to classify the extend of similarity between two EMG-curves of the same muscle during the same movement phase, according to the shape of the linear envelope of the raw EMG-signal.

Since the swim start is an acyclic movement, conform patterns that are characterized by a reverse activation of agonists and antagonists could not be found. Since such phenomena primarily occur in cyclic movements, this category was dropped. The remaining three criteria (*ID*entical, *AN*alogue, *DI*fferent) led to a modified "IDANDI"-system indicating three different levels of muscular specificity. Furthermore, in contrast to Bollens and Clarys (1988) we did not use the three point-score within each category that quantifies the degree of the differences in the time duration on the one hand, and the amplitude of the muscle activation on the other hand, or in both modalities. Differences in one of these or both modalities were all summarized in the category "analogue" patterns in the respective phase of the start movement.

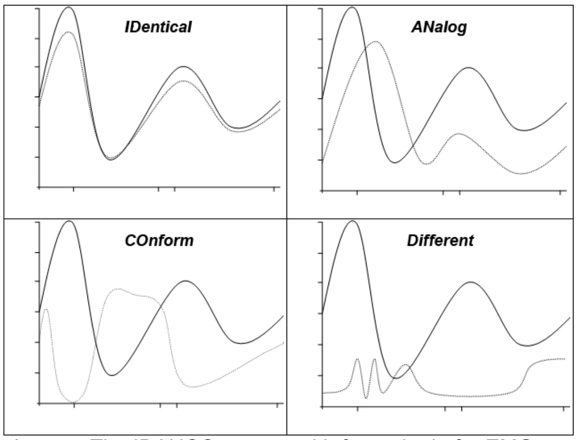

Figure 2. The IDANCO-system with four criteria for EMG pattern similarity (Bollens, Annemans, Vaes & Clarys, 1988).

Results

In a first step, kinematic and kinetic parameters of the whole body movement during the different phases of the backstroke start of all nine swimmers were measured. Table 2 shows the kinematic and kinetic data of the nine athletes during the backstroke start.

Significant correlations were found between the times of hands off and take off of the feet (r [9] = .70, p = .04), and between the times of hands off and hip entry (r [9] = .92, p < .001).

Other start parameters (wall and flight time, take off velocity and underwater speed) did not show systematic interrelations. Furthermore, in the elite swimmers the resultant (absolute) peak force just before the take off of the feet is significantly correlated with the final over all start time over 7.5 m (r [9] = -.82, p = .006). Likewise, a significant

Table 2

Kinematical and kinetical data (F_{RMax1}= resultant peak force at the date hands off and F_{RMax2}= resultant peak force during pres-

athletes	body mass [kg]	F_{RMax1} [N]	F_{RMax2} [N]	hands off [s]	take off [s]	hip entry [s]	start time 7.5 m [s]	$v_{take\ off}$ [$m \cdot s^{-1}$]	best time 50 m [s]
T.H.	82,0	980,8	1043,4	0,44	0,77	1,07	3,34	4,72	25,66
R.K.	88,0	941,2	1066,8	0,41	0,75	0,95	3,01	4,18	26,08
T.E.	71,0	764,1	742,3	0,48	0,82	1,10	3,69	3,75	26,89
J.G.	70,0	691,8	710,4	0,43	0,67	1,03	3,69	2,73	28,40
T.R.	75,0	777,8	922,1	0,47	0,77	1,10	3,59	2,95	24,80
R.P.	78,0	834,5	1018,1	0,59	0,87	1,19	3,52	2,74	28,10
H.M.	73,0	875,3	1055,6	0,53	0,76	1,17	2,72	2,92	26,16
M.C.	80,0	1124,0	984,0	0,45	0,67	1,04	3,23	3,56	25,53
S.D.	90,0	1098,1	1243,9	0,49	0,78	1,08	2,77	3,50	25,14
M	78.55	898.6	976.3	0.48	0.76	1.08	3.29	3.45	26.31
SD	±7.14	±149.7	±166.1	±0.06	±0.07	±0.07	±0.38	±0.69	±1.26

correlation between the absolute take off force measured under the laboratory conditions, and the official competition start times (head passing 7.5 m) could be found in those eight athletes that participated three days before the date of the measurements in the German national swimming championships 2005 (r [8] = -.78; p = .02).

The analysis of the kinetic data of the force distribution on the pool wall leads to an average curve of the time normalized horizontal (F_Z) and resultant forces (F_R) measured in the nine individuals (see figure 3). This force curve is characterized by a higher maximum peak force in the jump phase (from hands off until the take off of the feet) in comparison to the maximum peak force during the earlier pressure phase (from first movement until hands off). In the case of the horizontal force the difference between the two local force maximums turned out to be significant (F_Z: t [8] = -2.45, p = .04, d = 0.49).

The EMG data of the eight investigated muscles of one participant and finalist in the 100 m backstroke event of the Olympic Games in Athens 2004 (see figure 4) represent a general model of the muscle activity pattern of the backstroke start. The start movement during the overwater phase is initiated by the M. deltoideus (see curve A in figure 4) that was very active to fix the body in a high start position close to the wall. In the jump phase after pushing the hands off the wall this muscle also helps to bring the shoulder backward into the take off position. In addition, M. semitendinosus (D) showed maximum activity during the explosive extension of the legs at the take off. In the flight phase M. erector spinae (B) contributed especially to form the bow of the body shortly before and during the water entry.

In the underwater glide phase the cyclic propulsion movement of the dolphin kick is characterized by high muscle activities of the M. deltoideus (A) and M. rectus femoris (C) during the upward and downward sweep, and by time lagged activities of the M. semitendinosus (D).

The interrater reliability of the IDANDI-System was tested by the comparison of each single judgement of two scientific experts in regard to the similarity of each pair of the muscle specific EMG-curves by means of the categories Identical, Analogue or Different of the IDANDI-system. The test

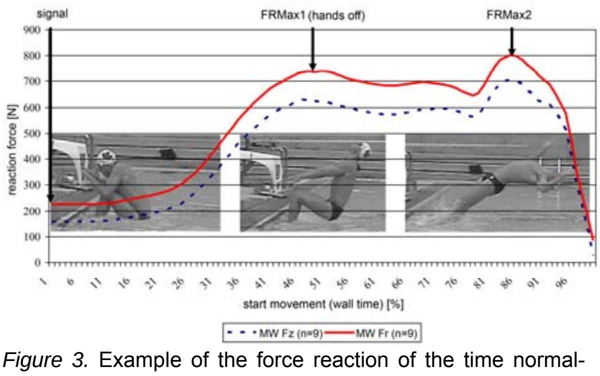

Figure 3. Example of the force reaction of the time normalized force curve of the start movement (N = 9).

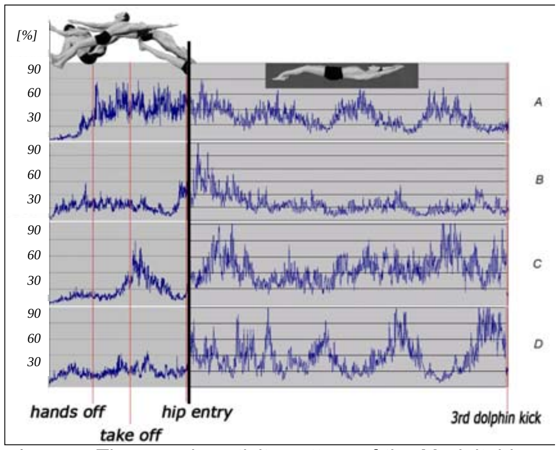

Figure 4. The muscle activity pattern of the M. deltoideus (A), M. erector spinae (B), M. rectus femoris (C), and M. semitendinosus (D) during the backstroke start movement of the athlete SD.

of the interrater reliability led to a Cohen's kappa of κ (288) = .66 (p < .05), and can be categorised as “good” (Robson, 2002).

The EMG recordings in the five swimmers that completed all four trials indicated a high repetition consistency and a high reproducibility of the identified patterns of muscle activity during the back stroke start (see figure 5). 13.0% of all patterns, that is 27 out of 208, proved to be identical, and 57.2% were at least analogue. Thus, 70.2% of all the linear envelopes showed some form of intraindividual reproducibility, and only 29.8% could not be held constant in the repeated trials of each athlete. Most of the identical patterns (85.2%) in the investigated muscles of the legs and the arms were found in the initial static hang phases I and II between the signal and the moment when the hands leave the wall, and in the following jump phase until the take off of the feet (11.1%). During the flight phase and especially during the water entry the number of different muscle activation patterns grows remarkably. After the body is fully immersed, the athletes start immediately with propulsive dolphin kicks. During the first dolphin kick 54.2% of the EMG recordings indicated analogue muscle activity patterns.

In fig. 5 the dominant label that the experts assigned to the movement behavior of the five backstrokers in the different phases of the swim start is marked by dark ellipses. The EMG recordings show clearly the increasing variability of the muscle activation of the swimmers along the different phases of the backstroke start. The athletes possess more or less identical EMG patterns in the initial hang phase. During the flight phase and especially during the water entry all investigated individuals exhibited a less specific activation of the relevant muscles. As the athletes performed different flight distances and showed a great variety in the way they adapted their movement behavior to the conditions of the water entry situation, the muscle activation from trial to trial was not identical any more, but in most cases analogue or even different. In the final glide phase the EMG recordings

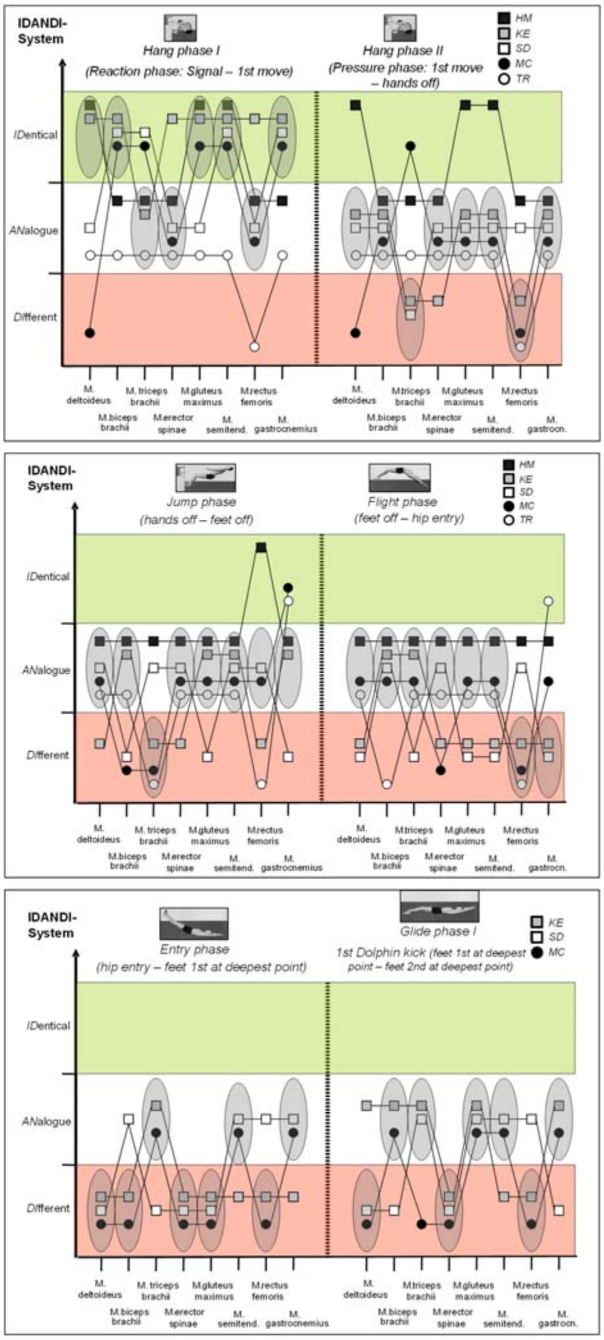

Figure 5. Comparison of the muscle activity patterns of five elite swimmers in the backstroke start

of the first dolphin kick demonstrated a more analogue movement behavior in the swimmers which is proof that the movement behavior of each individual is becoming more constant again.

Discussion

Although 7.5 m is a very short distance to measure the swim start performance, the athletes exhibit remarkable differences in the overall start times, which confirms the findings of Graumnitz and Küchler (2007) in world class athletes under the conditions of international competitions.

The importance of the kinematic and kinetic parameters of the above water phase (wall and flight activity) for the performance in the backstroke start technique is clearly shown by the analysis. High correlations occur between the resultant peak force short before the time of take off from the wall and the overall start time at 7.5 m. A higher impulse on the pool wall leads to a higher acceleration and take off velocity in the backstroke start. This is in line with the findings of e.g. Issurin and Verbitsky (2003), Krueger et al. (2003), Miller, Allen, and Pein (2003), Vilas-Boas et al. (2003), Lytle and Benjanuvatra (2004), Hohmann et al. (2006), and Mason, Alcock, and Fowlie (2006) that a high impulse during the jump phase is crucial for fast start times (head 7.5 m) in the backstroke start as well as in other start techniques (e.g. grab or track start). Although these results are in accordance with the literature on the biomechanical structure of the backstroke start in elite backstroke swimming, it has to be noted that the constraints of the study situation may have contributed to slower start times ($M_{\Delta t} = 0.76$ s) in the investigated athletes compared to their 7.5 m start times in official races. For example, in the semifinals and finals of the Swimming World Championships 2007, two participants of our study (*T.R. and S.D.*) showed better start times. Specifically, the wall times were Δt (*T.R.*) = 0.12 s, resp. Δt *(S.D.)* = 0.09 s faster than in the trials investigated two years earlier.

In contrast to former EMG studies on the grab and track start technique of female crawl sprinters (Krueger et al., 2003) the EMG recordings of the five male national team members investigated in this study gave a very distinct indication of (a) a high repetition consistency and (b) a high reproducibility of the identified patterns of muscle activity during the backstroke start. This is obviously true during the initial hang phase and the final glide phase. In the middle part of the start movement, that is during the flight phase and the water entry, the dynamic involvement of the propulsion and equilibrium muscles led to greater intra- and interindividual variability in the electromyographic muscle activities. This may be caused by the necessity to adapt the specific movement behavior to the varying situational constraints of the transition from above water to underwater conditions, like e.g. flight height and distance, angle and depth of water entry. After the athlete is fully immersed, the more standardized propulsive up and down sweeps of the dolphin kicks lead to more constant muscle activity patterns again.

The electromyographic findings suggest that the flight movement required more activity from the stabilisation apparatus of the back and the arms, rather than from the propulsion muscles of the legs probably because of the high water resistance during the water entry of the body (Cabri et al., 1992).

The myographic behavior expresses great similarities in the muscle activation patterns and thus allowed to form a representative 6-phase model of the muscle participation in the separate above water und underwater phases of the backstroke start. The muscle areas were selected with great care and the electrodes were fixed. Nevertheless it has to be taken in consideration that in every athlete the identical motor units were not always met. Furthermore, movement artefacts may have occured during the measurements, since the swimmers had to pull the 20 m long electrode cables alongside.

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