



Kinematic analysis of the kick start from OSB12

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Abstract

Introduction: Start performance in swimming plays a major role in determining the final standings, especially in sprint races. The purpose of the study was to determine kinematic parameters underlying the kick start from OSB12 in terms of the kick plate position and shoulder positioning at the start. **Material and methods:** The sample included 8 non-randomly recruited performance-level swimmers whose average age, body height, and body weight was 17.4 ± 1.8 years, 182.2 ± 3.4 cm and 81.00 ± 3.9 kg, respectively. To measure the kinematic parameters, we used the SwimPro camera system. The parameters measured included angular parameters and kinematic parameters for each of the start phases: block phase, flight phase, and water phase. We processed the collected biomechanical data using the Statistica 12.0 software. To determine significant differences between the kick plate positions in three types of start, we applied the Mann-Whitney U test. **Results:** We found significant differences ($p < 0.05$) in the selected kinematic parameters in all phases, which depended on the OSB12 kick plate position and basic starting position (front-, neutral-, and rear-weighted). The greatest differences in the parameters measured were found between the front-weighted start and rear-weighted start. We may conclude that performance-level swimmers should adjust the rear kick plate to positions 3 and 4 and assume the following starting position: front knee angle between 131° and 133° , rear knee angle around 80° , and trunk angle between 40° and 41° . This starting position affects the flight phase, namely takeoff angle (40° - 41°), head position at takeoff (1.33-1.38 m), flight time and distance (0.346-0.368 s; 2.74-2.79 m), entry angle (38°). The starting position also affects the glide phase, namely the glide time and distance (0.532-0.536 s; 2.22-2.26 m) and maximum depth (-0.91-0.92 m). **Conclusions:** The results of the study show that swimmers produced shorter times to 5 meters and higher velocity at 5 meters compared with other starting positions and OSB12 kick plate positions.

Keywords: swimming, water sports, movement analysis, kinematics

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INTRODUCTION

Start performance in swimming plays a major role in determining the final standings, especially in sprint races. The addition of a new start block in competitive swimming, the OSB11 with incline kick plate, has led to the development of a new starting technique, the kick start. Although some swimmers have limited access to these blocks, their approach to using it may determine their level of success [1]. This new start block gave rise to the researchers and academics focused more on the start techniques on this new start block. Kick start is a superior technique compared with the track start and grab start due to the larger base of support on the block to improving the stability of start and the larger take-off velocity as well as time advantages in the different start periods. Therefore, swimmers may develop increased force on the block, produce shorter flight time and longer flight distances [2]. Highly skilled swim-starts are distinguished in terms of several factors: reaction time from the start signal to the impulse on the block, including the control and regulation of foot force and foot orientation during takeoff, appropriate amount of glide time before leg kicking commences [3]. A variety of studies dealt with the effects of the kick start on performance relative to the track start [4-9]. In other studies, authors examined the effect of different starting positions on the start performance phases (block phase, flight phase, and underwater phase) [6, 10-12]. In the study by Barlow [10], front-weighted kick-start showed shorter movement time, block time than neutral and rear weighted kickstart. Rear-weighted kick-start showed shorter time to 5 and 15 m. The study by Kibele et al. [13] showed that forward and higher CoM position on the block with a narrow stance of the back plate and a forward and lower centre of mass position on the block with a wide stance of the back plate showed the highest advantages in the block time, horizontal peak force and time to 5 m. For kick start, several studies were made with the objective to determine the best back plate configuration as well as an optimal body position on the block. Concerning to this, contradictory results were observed with respect to the advantages provided to swimmers. Different studies associated these contradictions to differences in the knee angle, which was shown an important parameter in the force production on the block. In this regard, an analysis about the advantages and disadvantages of different back plate configurations and CoM position including the knee angle as an angular parameter seems to be required [14]. However, none of the studies has dealt with multiple start performance parameters in relation to the kick plate adjustment and shoulder positioning.

The purpose of the study was to determine kinematic parameters underlying the kick start from OSB12 in terms of the kick plate position and shoulder positioning at the start.

MATERIAL AND METHODS

Participants

The sample included 8 non-randomly recruited performance-level swimmers whose average age, body height, and body weight was 17.4 ± 1.8 years, 182.2 ± 3.4 cm and 81 ± 3.9 kg, respectively. The swimmers participated regularly in the Slovak regional swimming championships and Slovak swimming championship, having competed in particular in sprint races and freestyle races. The swimmers who participated in this study were selected from a sample of 40 swimmers according to their level of swimming performance. When tested, all swimmers were healthy and did not report any health problems before the testing. Each tested person read an information leaflet about testing and gave his or her written consent.

Testing protocol

The testing session took place in the morning at the swimming pool facilities of the Faculty of Sports, Presov, Slovakia. Each of the swimmers was informed about the testing conditions. Swimmers first had to determine their regularly used starting position on the OSB12 starting block. This was followed by a standard warm-up protocol and swimming over the course of 400 meters. After the warm-up, eleven waterproof adhesive markers were applied on swimmers' bodies: (1) lateral margin of the left transverse tarsal joint, (2) lateral left and right malleolus, (3) lateral left and right knee condyle, (4) left and right greater trochanter, (5) lateral margin of the left and right scapular spine,

Table 1. Definition of parameters

Phase	Variable	Definition
Block	Knee angle [°]	Hip/knee/ankle at the set position
	Hip angle [°]	Ankle/hip/shoulder
	Block time [s]	Starting signal/first sensible movement
Flight	Takeoff angle [°]	Horizontal/hip/block edge
	Head position [m]	Maximal distance of the head from the water surface at takeoff
	Time 2 m [s]	Starting signal/head crosses the 2 m
	Velocity 2 m [m/s]	Starting signal/head crosses the 2 m
	Flight time [s]	Takeoff/hands touch the water
	Flight distance [m]	Takeoff/hands touch the water
	Entry angle [°]	Horizontal/fingertips/hip joint
Water	Glide time [s]	Hands touch the water/head crosses the 5 m)
	Glide distance [m]	Hands touch the water/head crosses the 5 m)
	Maximal depth	Hands touch the water/head crosses the 5 m)
	Time 5 m [s]	Starting signal/head crosses the 5 m

(6) lateral left and right elbow epicondyle, (7) ulnar styloid process of the left and right wrist, (8) medial side of the 5th metacarpal-phalanx joint. After that swimmers performed three trial kick starts from the OSB12 starting block to become familiar with the three basic starting positions: front-weighted, neutral-weighted, and rear-weighted start.

To determine the starting position, we placed a 2 cm thick bar perpendicularly to the front edge of the starting block. The body position in the basic position on the starting block was determined according to the spot marked on the scapular spine. When this spot was located in front of the bar, the starting position was front-weighted. When the spot overlapped with the bar, the starting position was neutral-weighted. When the spot was located behind the bar, the starting position was rear-weighted. Swimmers took their marks and responded to a sound signal and a LED light signal at the same time. The swimmers started from starting positions and adjusted the kick plate to positions 1 through 5. Each of the swimmers performed 3 starts from all three positions (front-, neutral-, and rear-weighted). The rest period between starts and the change in the OSB12 kick plate position was 30 seconds and 2 minutes, respectively. Each swimmer performed a total of 45 jumps.

To measure the kinematic parameters (Table 1), we used the SwimPro camera system (RJB Engineering Australia Pty Ltd.). The first camera was perpendicular to the starting block in the 0 m distance from the edge of the pool and 1.5 m above the water surface. The second camera was 1.6 m from the edge of the pool and 1.5 m under the water surface. The third camera was 1.6 m from the edge of the pool and 1.7 meters below the water surface. The fourth camera was 5 m away from the edge of the pool and 1.7 m below the water surface. To increase the level of lighting, we used halogen and additional LED lights. The camera system was operating at 60 frames per second and the shutter speed was set at 1/1000s. The video recording was subsequently assessed using the Dartfish© software (Dartfish ProSuite4.0, 2005; Switzerland). This software meets the validity and reliability criteria for the assessment of kinematic parameters using the 2D analysis in swimming [15, 16]. We processed the collected biomechanical data using the Statistica 12.0 software (TIBCO Software Inc.). To determine significant differences between the kick plate positions in three types of start, we applied the Mann-Whitney U test.

RESULTS

Block phase

We found significant differences ($p < 0.05$) in the selected kinematic parameters in all phases, which depended on the OSB12 kick plate position and basic starting position (front-, neutral-, and rear-weighted). The greatest differences relative to the kick plate position were found between the front-weighted start and rear-weighted start (Table 2).

Table 2. Significant differences between kick starts relative to kick plate position

No.	Front-weighted [°]		Neutral-weighted [°]		Rear-weighted [°]	
	Mean	SD	Mean	SD	Mean	SD
1	7.8*	0.6	0.0*	0.0	-6.2*	0.6
2	7.8*	0.8	0.0*	0.0	-5.4*	0.4
3	7.4*	0.7	0.0*	0.0	-5.9*	0.5
4	7.1*	0.9	0.0*	0.0	-6.0*	0.7
5	8.2*	0.8	0.0*	0.0	-6.0*	0.4

1-5 kick plate position; * - $p < 0.05$

The starting position on the starting block forms the basis for optimum start performance as it affects its subsequent phases. The front knee angle in the starting position on the starting block increased, depending on the shoulder position at the start and the kick plate position on the OSB12 starting block. In the front-weighted start, the front knee angle values were lower (125° - 128°) compared to the neutral-weighted start (128° - 130°) or rear-weighted start (130° - 133°). The largest knee angle ($132.7^{\circ} \pm 1.8^{\circ}$) in the basic starting position was recorded for the rear-weighted start with kick plate in position 3. The lowest front knee angle ($124.8^{\circ} \pm 1.9^{\circ}$) was recorded for the front-weighted start with kick plate in position 1 (Table 3).

The rear knee angle for the leg placed against the rear kick plate on the OSB12 starting block decreased depending on both the kick plate position and the shoulder position at the start. In the front-weighted start, the rear knee angles were larger (88° - 96°) than in the neutral-weighted start (80° - 86°) and rear-weighted start (77° - 82°). The largest rear knee angles ($96.0^{\circ} \pm 1.6^{\circ}$) were found for the front-weighted start with kick plate in position. The lowest rear knee angle ($76.7^{\circ} \pm 1.5^{\circ}$) was found for the rear-weighted start with the kick plate in position 2 (Table 3).

The trunk angle in the basic starting position decreased depending on both the kick plate position and shoulder position. The trunk angles in the front-weighted start were larger (46° - 48°) than those in the neutral-weighted start (43° - 47°) and rear-weighted start (41° - 45°). The largest trunk angle ($48.3^{\circ} \pm 1.2^{\circ}$) was recorded for the front-weighted start with the kick plate in position 3. The lowest trunk angle ($41.3^{\circ} \pm 0.9^{\circ}$) was recorded for the rear-weighted start with the kick plate in position 5 (Table 3).

The results of the study showed that swimmers produced the fastest reactions when the front-weighted (0.833-0.891 s) and neutral-weighted starts (0.878-0.910 s) were used. These reactions were produced across all kick plate positions on the OSB12 starting block. The shortest start reaction (0.833 ± 0.066 s) was found the front-weighted start when the kick plate was adjusted to position 3. The longest start reaction was found for the rear-weighted start with the kick plate in position 1 on the OSB12 starting block (Table 3).

We found significant differences ($p < 0.05$) in the selected kinematic parameters in all phases, which depended on the OSB12 kick plate position and basic starting position (front-, neutral-, and rear-weighted). The greatest differences relative to the kick plate position were found between the front-weighted start and rear-weighted start (Table 2).

Statistically significant differences ($p < 0.05$) in the basic starting position on the OSB12 starting block in the front knee angle, rear knee angle, trunk angle, block time were found in particular between the front-weighted start and rear-weighted start for various OSB12 kick plate positions (Table 3).

Flight phase

The flight phase is determined by the starting position on the starting block. The values of takeoff angles increased depending on the shoulder position in the basic starting position and kick late position on the OSB12 starting block. The takeoff angle in the front-weighted start across all kick plate positions (33° - 37°) was lower than in the neutral-weighted start (35° - 38°) and the rear-weighted start (38° - 41°). The largest takeoff angle ($41.0 \pm 1.3^{\circ}$) was found for the rear-weighted start with the kick plate in position 3 and the lowest takeoff angle was found for the front-weighted start with the OSB12 kick plate in position 1 (Table 4).

Table 3. Significant differences in block phase parameters

Position	Indicator	Front knee [°]	Rear knee [°]	Trunk [°]	Block time [s]
1F	M	124.8 ^{3R,5R}	87.9	47.0 ^{5R}	0.890 ^{1R,3-4R}
	SD	1.9	1.3	1.1	0.039
1N	M	128.8	86.4	43.9	0.894
	SD	1.7	1.3	1.0	0.031
1R	M	131.0 ^{4F}	78.4 ^{2-5F}	42.7 ^{3-5F}	0.917 ^{2-5F}
	SD	1.5	1.1	1.2	0.082
2F	M	125.3 ^{3R,5R}	90.3 ^{2R}	46.3	0.891
	SD	1.8	1.5	1.4	0.039
2N	M	127.5 ^{3R}	82.6	43.4	0.906
	SD	1.8	0.9	0.8	0.053
2R	M	131.4	76.7 ^{3-5F}	42.2 ^{3-5F}	0.916 ^{3-5F}
	SD	1.8	1.5	0.5	0.050
3F	M	127.9	90.3	48.3 ^{5R}	0.833 ^{3-4R}
	SD	1.0	1.4	1.2	0.066
3N	M	130.3	80.3 ^{5F}	46.7	0.889
	SD	1.9	1.5	0.8	0.049
3R	M	132.7 ^{4F}	79.5 ^{3-5F}	44.9	0.907
	SD	1.8	1.2	1.3	0.065
4F	M	125.3 ^{5R}	93.5 ^{4R}	47.5 ^{5R}	0.848 ^{4-5R}
	SD	1.2	1.7	0.9	0.069
4N	M	128.6	86.2	45.1	0.878
	SD	1.7	1.0	1.2	0.071
4R	M	130.6	80.4 ^{5F}	43.3	0.881
	SD	1.5	1.1	1.4	0.052
5F	M	127.9	96.0	47.5 ^{5R}	0.877
	SD	1.6	1.2	1.2	0.065
5N	M	130.0	86.3	42.8	0.910
	SD	1.7	1.5	1.5	0.044
5R	M	132.5	82.1	41.3	0.911
	SD	1.0	0.9	0.9	0.034

1-5 kick plate position; F- front; N - neutral; R- rear; ^{1-5F-R} - $p < 0.05$

The head position at takeoff expressed as the distance of the head from the water surface increased depending on the basic starting position on the OSB12 starting block. When swimmers used the front-weighted start and took off the starting block, the head was in a lower position (1.20-1.32 m) compared with the neutral-weighted (1.23-1.33 m) and rear-weighted starts (1.26-1.38 m). The highest head height (1.38 ± 0.01 m) was recorded in the rear-weighted start with the kick plate in position 4. The lowest head position (1.20 ± 0.02 m) was recorded in the front-weighted start with the OSB12 kick plate in position 1 (Table 4).

Swimmers produced faster times to 2 meters (0.998-1.066 s) across all kick plate positions and achieved higher velocities (1.877-2.006 m/s) when using the front-weighted start compared with the neutral-weighted (1.025-1.103 s; 1.813-1.955 m/s) or rear-weighted start (1.041-1.105 s; 1.812-1.925 m/s). The shortest time to 2 meters (0.998 ± 0.035 s) and highest velocity at 2 meters (2.006 ± 0.071 m/s) were found for the front-weighted start with the kick plate in position 4. The longest time to 2 meters (1.105 ± 0.035 s) and lowest velocity at 2 meters (1.812 ± 0.059 m/s) were found for the rear-weighted start with the OSB12 kick plate in position 1 (Table 4).

The duration of flight phase increased depending on the position on the starting block and the position of OSB12 kick plate, which was associated with flight distance. Flight time in the rear-

weighted start across all OSB12 kick plate positions was shorter (0.343-0.368 s) than in the neutral-weighted start (0.346-0.373 s) or front-weighted start (0.362-0.392 s). The shortest flight time (0.343 ± 0.024 s) was recorded for the rear-weighted start with the kick plate in position 2. The longest flight phase (0.392 ± 0.052 s) was recorded for the front-weighted start with the OSB12 kick plate in position 3. The flight distance in rear-weighted start across all kick plate positions was longer (2.52-2.79 m) than in the neutral-weighted (2.51-2.73 m) or front-weighted (2.48-2.72 m) starts. The longest flight distance (2.79 ± 0.10 m) was recorded for the rear-weighted start with the kick plate in position 4. The shortest flight distance (2.48 ± 0.06 m) was recorded for the front-weighted start with the OSB 12 kick plate in position 1 (Table 4).

Table 4. Significant differences in flight phase parameters

Position	Indicator	Takeoff angle [°]	Head position [m]	Time to 2 m [s]	Velocity to 2 m [m/s]	Flight time [s]	Flight distance [m]	Entry angle [°]
1F	M	32.7 ^{1-4R}	1.20 ^{2,4-5R}	1.066	1.877	0.383 ^{1-5R}	2.48 ^{1-5R}	34.0 ^{1-4R}
	SD	0.8	0.02	0.032	0.057	0.019	0.06	1.3
1N	M	34.8	1.23 ^{2,4-5R}	1.103	1.813	0.366	2.51	35.4
	SD	1.6	0.02	0.013	0.021	0.055	0.07	1.6
1R	M	38.5	1.26 ^{2,4F}	1.105 ^{3-5F}	1.812 ^{3-5F}	0.344	2.52 ^{4-5F}	36.0
	SD	1.1	0.03	0.035	0.059	0.041	0.06	0.8
2F	M	36.7	1.30	1.024	1.959	0.362	2.62 ^{2-4R}	34.4
	SD	1.1	0.02	0.058	0.109	0.028	0.09	1.4
2N	M	37.6	1.31	1.065	1.882	0.346	2.71	36.2
	SD	1.2	0.02	0.049	0.090	0.045	0.10	1.3
2R	M	39.6	1.37	1.068 ^{3-5F}	1.878 ^{3-5F}	0.343	2.72	36.7
	SD	0.9	0.01	0.052	0.094	0.024	0.09	1.3
3F	M	36.7	1.29	0.999 ^{3-4R}	2.003 ^{3-4R}	0.392	2.69	35.1
	SD	0.7	0.01	0.022	0.045	0.052	0.12	1.1
3N	M	37.1	1.32	1.032	1.940	0.370	2.69	35.6
	SD	1.4	0.03	0.038	0.071	0.049	0.10	0.9
3R	M	40.6 ^{4-5F}	1.33	1.052	1.905	0.346 ^{4-5F}	2.74 ^{4-5F}	37.7 ^{4-5F}
	SD	1.3	0.01	0.056	0.102	0.032	0.11	1.1
4F	M	35.7 ^{4R}	1.32	0.998	2.006	0.385	2.72	35.6 ^{4R}
	SD	1.0	0.01	0.035	0.071	0.046	0.09	1.1
4N	M	36.3	1.33	1.025	1.955	0.373	2.73	37.6
	SD	1.0	0.02	0.048	0.095	0.034	0.09	1.1
4R	M	40.0 ^{5F}	1.38	1.041	1.925	0.368	2.79	38.4 ^{5F}
	SD	1.1	0.02	0.045	0.085	0.030	0.10	1.3
5F	M	35.1	1.30	1.007	1.990	0.365	2.70	35.1
	SD	1.3	0.02	0.038	0.077	0.043	0.11	1.3
5N	M	36.7	1.32	1.034	1.935	0.361	2.71	38.0
	SD	1.3	0.02	0.024	0.045	0.064	0.12	1.1
5R	M	38.1	1.35	1.063	1.882	0.354	2.73	40.0
	SD	1.1	0.01	0.029	0.051	0.051	0.10	1.7

1-5 kick plate position; F- front; N – neutral; R- rear; ^{1-5F-R} – $p < 0.05$; significant differences in kick starts relative to kick plate position

Table 5. Significant differences in water phase parameters

Position	Indicator	Glide time [s]	Glide distance [m]	Max depth [m]	Time to 5 m [s]	Velocity to 5 m [m/s]
1F	M	0.582 ^{3-5R}	2.52 ^{1-5R}	-0.76 ^{2-5R}	1.856 ^{2-4R}	2.698 ^{2-4R}
	SD	0.056	0.06	0.03	0.072	0.104
1N	M	0.580	2.49 ^{4-5R}	-0.78	1.839	2.724
	SD	0.067	0.07	0.02	0.088	0.131
1R	M	0.571	2.48 ^{4-5F}	-0.81	1.832 ^{4-5F}	2.735 ^{4-5F}
	SD	0.046	0.06	0.02	0.082	0.124
2F	M	0.568	2.38 ^{2-4R}	-0.75 ^{2-5R}	1.822 ^{2-4R}	2.746 ^{2-4R}
	SD	0.035	0.09	0.04	0.044	0.066
2N	M	0.566	2.29	-0.80	1.818	2.754
	SD	0.037	0.10	0.01	0.059	0.092
2R	M	0.534	2.28	-0.90	1.793 ^{4-5F}	2.791 ^{4-5F}
	SD	0.037	0.10	0.03	0.052	0.081
3F	M	0.595 ^{3-4R}	2.31 ^{3-4R}	-0.80 ^{3-4R}	1.820 ^{3-4R}	2.751 ^{3-4R}
	SD	0.037	0.12	0.03	0.061	0.093
3N	M	0.548	2.31	-0.89	1.807	2.773
	SD	0.045	0.10	0.02	0.082	0.136
3R	M	0.532 ^{4-5F}	2.26	-0.91	1.785 ^{4-5F}	2.807 ^{4-5F}
	SD	0.052	0.11	0.03	0.088	0.138
4F	M	0.587 ^{4R}	2.28 ^{4R}	-0.82 ^{4R}	1.820 ^{4R}	2.750 ^{4R}
	SD	0.051	0.09	0.03	0.058	0.087
4N	M	0.545	2.27	-0.88	1.796	2.790
	SD	0.067	0.09	0.02	0.082	0.128
4R	M	0.536	2.22	-0.92	1.785 ^{5F}	2.807 ^{5F}
	SD	0.048	0.10	0.02	0.057	0.089
5F	M	0.597	2.30	-0.83	1.833	2.723
	SD	0.039	0.11	0.02	0.069	0.119
5N	M	0.562	2.30	-0.88	1.836	2.726
	SD	0.044	0.12	0.02	0.063	0.095
5R	M	0.559	2.27	-0.92	1.825	2.741
	SD	0.049	0.10	0.03	0.026	0.040

1-5 kick plate position; F- front; N - neutral; R- rear; ^{1-5F-R} $p < 0.05$; significant differences between kick start positions

The entry angles increased depending on the position on the starting position and the OSB12 kick plate position. The entry angle in the rear-weighted start across all kick plate positions was larger (36-40°) than in the neutral-weighted (35°-38°) or front-weighted (34°-36°) starts. The largest entry angle (40° ± 1.7°) was recorded for the rear-weighted start with the kick plate in position 5. The lowest entry angle was recorded for the rear-weighted start with the OSB12 kick plate in position 1 (Table 4).

Water phase

The swimmers included in our study were not allowed to perform any kicking or undulating movements. The glide time and glide phase increased depending on the position on the starting block and the OSB12 kick plate position. The glide time in the rear-weighted start across all kick plate positions was shorter (0.532-0.571 s) than in the neutral-weighted (0.545-0.580 s) and front-weighted start (0.568-0.597 s). The shortest glide time (0.532 ± 0.052 s) was recorded when the swimmers used the rear-weighted start with the kick plate in position 3. The longest glide time (0.597 ± 0.039 s) was recorded when the swimmers used the front-weighted start and adjusted the OSB12 kick plate to

position 5. As for the glide distance, shorter glide distance (2.22-2.48 m) was recorded across all kick plate positions when the rear-weighted start was used compared with the neutral-weighted start (2.27-2.49 m) and front-weighted start (2.28-2.52 m). The shortest glide distance (2.22 ± 0.10 m) was recorded when swimmers used the rear-weighted start and adjusted the OSB12 kick plate to position 4. The longest glide distance (2.52 ± 0.06 m) was recorded when swimmers used the front-weighted start and the OSB12 kick plate was in position 1 (Table 5).

Maximum depth upon entry into water increased depending on the position on the starting block and the OSB12 kick plate position. Maximum depth was greater across all kick plate positions in the rear-weighted start (-0.81-0.92 m) than in the neutral-weighted start (-0.78-0.88 m) and front-weighted start (-0.75-0.83 m). The highest value of maximum depth (-0.92 ± 0.02 m) was recorded when swimmers used the rear-weighted start and the kick plate was in position 5. The lowest value of maximum depth (-0.75 ± 0.04 m) was recorded when swimmers used the front-weighted start and the OSB12 kick plate was adjusted to position 2 (Table 5).

Swimmers produced shorter times to 5 meters (1.785-1.832 s) across all kick plate positions and higher velocities (2.735-2.807 m/s) in the rear-weighted start than in the neutral-weighted start (1.796-1.839s; 2.724-2.790 m/s) and front-weighted start (1.820-1.856 s; 2.698-2.750 m/s). The shortest time to 5 meters (1.785 ± 0.088 or 0.057 s) and highest velocity (2.807 ± 0.137 or 0.057 m/s) was recorded when swimmers used the front-weighted start and the kick plate was in positions 3 or 4. The longest time to 5 meters (1.856 ± 0.072 s) and lowest velocity (2.698 ± 0.104 m/s) was recorded when swimmers used the front-weighted start and the kick plate was adjusted to position 1 (Table 5). Statistically significant ($p < 0.05$) differences in the water phase parameters were found in particular between the front-weighted start and rear-weighted start across all OSB12 kick plate positions in all parameters measured (Table 5).

DISCUSSION

The purpose of the study was to determine kinematic parameters underlying the kick start from OSB12 in terms of the kick plate position and shoulder positioning at the start. Most studies [1, 17, 18] which dealt with the starts from the new OSB starting block have focused neither on all kick plate positions nor on various modifications of the body positions at the start [1, 10, 13]. In our study, we deal with all variants of the OSB12 kick start in terms of the kick plate position and body position at the start, not with two positions (+-) from the preferred kick plate positions or modification of the body position relative to the preferred kick plate positions. We provide a complex overview of kinematic characteristics for the OSB12 kick start.

The block phase accounts for 11% of the start performance in swimming [19]. In our study, the block phase contributed 46% to 51% to the start performance (5 m) depending on the OSB12 kick plate position and shoulder position at the start. This basic phase affects performance in the subsequent phases of the start [20], which depends on the modifications of the basic starting position and adjustment of the rear kick plates. The back plate increased the force developed on the block reducing the block time (i.e. increase of explosive force) and the response time to the starting signal and increasing the development of the horizontal and vertical accelerations [7, 9, 21]. Nomura et al. [8] showed larger acceleration values 0.3 s just before the takeoff for KS than for TS, with differences of 0.80 m/s^2 and -0.42 m/s^2 for horizontal and vertical component, respectively. Furthermore, Slawinski et al. [22] observed the peak of acceleration when the rear foot pushed on the back plate, in less than 0.15 s. Consequently, swimmers are able to obtain larger temporal advantages before at takeoff of the rear foot as well as higher horizontal force which let shorter block time and larger horizontal takeoff velocity values. Some studies [1, 10, 13, 22] focused on the kick start and the modifications of the starting position on the OSB starting block: front-weighted, neutral-weighted, and rear-weighted. Slawinski et al. [22] found that closer horizontal projection on the starting block at takeoff is associated with higher horizontal takeoff velocity and shorter start reaction. However, later studies showed shorter block time, horizontal takeoff velocity and flight distance as well as longer time to 5 and 15 m in front-weighted start than in the rear-weighted start [13]. In our study, swimmers reacted faster from all OSB12 kick plate positions when the front-weighted and rear-weighted starts were used ($p < 0.05$). The differences in the results reported by Slawinski et al. [22] and Seifert et al. [15] for

various OSB kick plate positions may have been caused by changes in the knee angles in the starting position. Front and rear knee angles are important parameters underlying the block performance because this is closely associated with the force production at the starting signal [23, 24]. In the kick start, the rear knee angle varies from 75° to 85°, and the front knee angle varies from 135° to 145°, which manifested in shorter start reaction and higher horizontal takeoff velocity [23, 24]. In our study, we recorded significant differences ($p < 0.05$) in knee angles, which depended on the shoulder positioning on the starting block and OSB12 kick plate positions. The shortest start reactions and times to 2 m were recorded when swimmers used the front-weighted start and the OSB12 kick plate was adjusted to positions 3 and 4 with the front knee angle from 125° to 128° and rear knee angle from 90° to 94°. Despite these findings the shortest time to 5 meters was recorded when the rear-weighted start from the kick plate in positions 3 and 4 was used and the front knee angle ranged from 131° to 133° and the rear knee angle was 80°.

The flight phase contributes 5% to the start time (15 m) [19]. In our study, the contribution of the flight phase to the 5-meter distance ranged from 19% to 22% depending on the OSB12 kick plate position and shoulder positioning. This phase is considerably affected by the previous phase. Horizontal takeoff velocity is an important performance-determining parameter in this phase. Flight time and flight distance are affected by the takeoff angle ($r = -0.59$; $r = 0.88$) [24] and by the start reaction [3, 8]. The entry angle is dependent on the takeoff angle ($r = 0.057$) [15]. When determining differences in the selected flight phase parameters, significant differences ($p < 0.05$) were found between the front-weighted start (kick plate in position 1) and other starts. The longest flight phase (2.74-2.79 m) ranging from 0.346 s to 0.368 s was recorded when the takeoff angle was 40° to 41° and head distance from the water surface ranged from 1.33 m to 1.38 m with subsequent water entry at 38° after the rear-weighted start with the kick plate in positions 3 and 4. These parameters resulted in the shortest times to 5 meters. The entry angle has been found to affect the depth and mean gliding velocity [26].

The glide phase and initial underwater motion contribute 56% to the time to 15 meters [19, 26]. In our study, the glide phase contributed 30% to 33% to the 5-meter distance, depending on the OSB12 kick plate position and shoulder positioning on the starting block. It should be noted that the glide phase time and distance are affected by the previous phase. The studies by Beretic et al. [4] a Ozeki et al. [9] showed that the entry angle ranged from 39° to 42°, however, we found that entry angle recorded when the fastest times were achieved in our study was about 38°. The fastest times to 5 meters were recorded when swimmers used the rear-weighted start and adjusted the OSB12 kick plate to positions 3 and 4. Significant differences ($p < 0.05$) were found in particular between the front-weighted start and rear-weighted start across all kick plate positions. Some studies dealt with the underwater phase in order to decrease water drag upon entry into water associated with velocity [26-28]. Tor et al. [28] found that should glide for at least 2 seconds at the maximum depth of 0.91 m to 0.92 m. The first kick should be performed at 6.5 m and the breakout distance should be 10.5 m. In multiple studies, start performance was assessed on the basis of times to 5 m and 15 m [4, 7, 9, 10]. In our study, we selected the 5-meter distance and instructed the swimmers not to perform any underwater kicking motion because we wanted to determine the swim start efficiency at this distance using various start modifications. The studies by Honda et al. [1] a Barlow et al. [10] show significant differences between the front-weighted, neutral-weighted, and rear-weighted starts, favoring the rear-weighted start, which was confirmed by our study as well.

CONCLUSION

Start performance in swimming is determining by its individual phases that follow each other. We found significant differences ($p < 0.05$) in the selected kinematic parameters in all phases, which depended on the OSB12 kick plate position and basic starting position (front-, neutral-, and rear-weighted). The greatest differences in the parameters measured were found between the front-weighted start and rear-weighted start. In terms of individual phases, the best block performance (block time - 3F, 4F) may manifest also during the flight phase (time to 2m - 3F, 4F) but not during the glide phase (time to 5 m - 3R, 4R). Therefore, we do not recommend swim coaches to assess start performance (15 m) according to the block time, which is displayed in the results of sprint races. We

may conclude that performance-level swimmers should adjust the rear kick plate to positions 3 and 4 and assume the following starting position: front knee angle between 131° and 133°, rear knee angle around 80°, and trunk angle between 40° and 41°. This starting position affects the flight phase, namely takeoff angle (40-41°), head position at takeoff (1.33-1.38 m), flight time and distance (0.346-0.368 s; 2.74-2.79 m), entry angle (38°). The starting position also affects the glide phase, namely the glide time and distance (0.532-0.536 s; 2.22-2.26 m) and maximum depth (-0.91-0.92 m). This resulted in shorter time to 5 meters and higher velocity at 5 meters compared with other starting positions and OSB12 kick plate positions.

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