


BLOCK SLOPE IS THE MAIN DETERMINANT OF BLOCK PHASE PERFORMANCE IN SWIMMING

A INCLINAÇÃO DO BLOCO É O PRINCIPAL DETERMINANTE DO DESEMPENHO DA FASE DE BLOCO EM NATAÇÃO

LA INCLINACIÓN DEL BLOQUE ES EL PRINCIPAL DETERMINANTE DEL DESEMPEÑO DE LA FASE DE BLOQUE EN NATACIÓN

Uğur ÖDEK¹ 
(Physical Education Professional)

Feza KORKUSUZ² 
(Medical Doctor, Orthopedic Surgeon)

Sadettin KIRAZCI³ 
(Physical Education Professional)

1. Nevşehir Hacı Bektaş Veli University, Physical Education and Sports Department, Nevşehir, Turkey.

2. Hacettepe University Medical Faculty, Department of Sports Medicine, Ankara, Turkey.

3. Middle East Technical University, Physical Education and Sports Department, Ankara, Turkey.

Correspondence:

Uğur ÖDEK, Nevşehir Hacı Bektaş Veli Üniversitesi Eğitim Fakültesi Beden Eğitimi ve Spor Eğitimi Bölümü 3. Kat oda no: 204 50300 Nevşehir, Turkey.
ugurodek@nevsehir.edu.tr

ABSTRACT

Introduction: Swimming starts are an important component for decreasing the total race time, especially in short events. In this phase of swimming, the aim is to increase performance using many different techniques and starting platforms. **Objectives:** The effects of height and slope of the starting block on kick-start performance were assessed in this study. **Methods:** Six male competitive swimmers performed 24 kick-starts using four block settings: 65 cm & 75 cm flat and 65 cm & 75 cm sloped. Two-dimensional kinetic and three-dimensional kinematic data were analyzed, including average and maximum horizontal/vertical forces and impulses; reaction times; movement and block times; and take-off vertical/horizontal velocities. Two-way within-subject design ANOVAs were implemented to test the effects of block height and slope on the kinetic and kinematic variables. **Results:** Block slope was the main factor affecting most of the dependent variables. Shorter block and movement times, greater average and maximum vertical forces, vertical impulse, and maximum horizontal force were found for the sloped settings. An inverse relationship was found between block height and 0-5 m times. **Conclusion:** Based on the results, blocks with height of 75 cm and slope of 10° provided better results in swimmers' performance in the block phase. **Level of evidence II, Therapeutic Studies - Investigating the Results of Treatment**

Keywords: Biomechanical phenomena; Kinetics; Kinematics; Swimming.

RESUMO

Introdução: As largadas de natação são um componente importante para reduzir o tempo total de competição, especialmente em eventos curtos. Nessa fase da natação, o objetivo é aumentar o desempenho usando várias técnicas e plataformas de largada distintas. **Objetivos:** Neste estudo, foram avaliados os efeitos da altura e da inclinação da plataforma sobre desempenho da saída kick-start. **Métodos:** Seis nadadores de competição do sexo masculino realizaram 24 largadas, usando quatro tipos de bloco de partida (65 cm e 75 cm de altura planos e 65 cm e 75 cm com inclinação). Foram analisados dados cinéticos bidimensionais e cinemáticos tridimensionais, incluindo forças e impulsos horizontais/verticais médios e máximos; tempos de reação, movimento e de bloco; e velocidades vertical/horizontal da decolagem. Empregou-se o método ANOVA bidirecional intraindivíduo para analisar os efeitos da altura e da inclinação do bloco sobre as variáveis cinéticas e cinemáticas. **Resultados:** A inclinação do bloco foi o principal fator que afetou a maioria das variáveis dependentes. Nas plataformas de largada inclinadas, verificou-se que os tempos de bloco e movimento eram mais curtos e as forças verticais médias e máximas, o impulso vertical e a força horizontal máxima foram maiores nas configurações inclinadas. Foi encontrada uma relação inversa entre a altura do bloco e os tempos para as distâncias de 0 a 5 metros. **Conclusões:** Com base nos resultados, os blocos com 75 cm de altura e 10 graus de inclinação forneceram melhores resultados de desempenho dos nadadores na fase de bloco. **Nível de Evidência II – Investigação dos resultados do tratamento.**

Descritores: Fenômenos biomecânicos; Cinética; Cinemática; Natação.

RESUMEN

Introducción: Las largadas de natación son un componente importante para reducir el tiempo total de competición, especialmente en eventos cortos. En esta fase de natación, el objetivo es aumentar el desempeño usando varias técnicas y plataformas de largada distintas. **Objetivos:** En este estudio, fueron evaluados los efectos de la altura y de la inclinación de la plataforma sobre desempeño de la salida kick-start. **Métodos:** Seis nadadores de competición del sexo masculino realizaron 24 largadas, usando cuatro tipos de bloque de partida (65 cm y 75 cm de altura planos y 65 cm y 75 cm con inclinación). Fueron analizados datos cinéticos bidimensionales y cinemáticos tridimensionales, incluyendo fuerzas e impulsos horizontales/verticales promedios y máximos; tiempo de reacción, movimiento y de bloque; y velocidades vertical/horizontal del despegue. Se empleó el método ANOVA bidireccional intraindividuo para analizar los efectos de la altura y de la inclinación del bloque sobre las variables cinéticas y cinemáticas. **Resultados:** La inclinación del bloque fue el principal factor que afectó a la mayoría de las variables dependientes. En las plataformas de largada inclinadas, se verificó que los tiempos de bloque y movimiento eran



más cortos y las fuerzas verticales promedio y máximas, el impulso vertical y la fuerza horizontal máxima fueron mayores en las configuraciones inclinadas. Fue encontrada una relación inversa entre la altura del bloque y los tiempos para las distancias de 0 a 5 metros. Conclusiones: Con base en los resultados, los bloques con 75 cm de altura y 10 grados de inclinación proporcionaron mejores resultados de desempeño de los nadadores en la fase de bloque.

Nivel de Evidencia II; Investigación de los resultados del tratamiento

Descriptor: Fenómenos biomecánicos; Cinética; Cinemática; Natación

INTRODUCTION

Swimming starts are accepted as a critical component of the total race time especially in short events.^{1,2} The start is divided into the block, the flight and the underwater phases that begin with the starting signal, the take-off and entry.³⁻⁶ The contribution of these phases to overall start performance can be approximated as 11%, 5% and 84%, respectively.⁵ Despite its relatively small contribution, the block phase has a significant effect on the following phases, since the take-off velocity and angle are determined in this phase.^{4,7}

In 2008, the Swiss company Omega made a distinctive modification on the blocks and produced a starting block (OSB11) with a footrest. Since 2009, they have been used in nearly all major competitions including, the 2012 and the 2016 Summer Olympics. OSB11's adjustable (in back and forth direction) 30°-sloped and 12cm-elevated footrest is placed at the back end of the block.⁸ The footrest changed the characteristics of the start technique on a large scale,⁹⁻¹² and consequently, a new starting technique called kick-start was emerged. Research on kick-start demonstrated a significant contribution of the footrest to the overall start performance.^{9,11,13,14} Studies that compared the kick-start and the traditional track-start indicated time improvements in 5m-7.5m, 10m and 15m distances.^{14,9,11} Shared findings of these studies pointed out an increase in both horizontal and vertical take-off velocities and decrease in movement time. Researchers associated these advancements to factors such as augmented rear leg involvement, the center of mass position and feet placement.^{14,9,10}

The effects of block height, block slope and both were investigated in previous studies.^{15,16-18,19} Cornett, White¹⁵ concluded that there was a non-linear relationship between block height,^{21,46,76} and head velocity and swimmer's head velocity at maximum depth when the preferred start technique was used. Stewart¹⁸ found the effect of block slope (0, 10°) on take-off velocity was non-significant for grab start. Elliot and Sinclair¹⁶ explored the effects of three block slopes (0, 10, 15°) and indicated a non-linear relationship regarding horizontal velocity. Stevenson and Morehouse¹⁷ used blocks that were sloped between 0-30°, and they found that 20° was the most advantageous slope for a grab start. On the other hand, they did not find a time difference between performances started on the 0° and 20° sloped blocks for 22.86m (25yards). Gehlsen and Wingfield¹⁹ indicated significant main effects of block height (.46, .56, .66, .76m) and slope (0, 10°) for the center of gravity velocity upon the water surface. According to their results, both vertical and resultant velocities were increased due to an increase in block height and slope. Nevertheless, none of these researchers instrumented a starting block with a footrest to measure the effects of different block installations on kick-start performance.

The scope of this study was to explore the effects of height and slope of the starting block with a footrest on swimming start. We hypothesized that block height and slope have effects on block phase of start. Research questions were whether block height and slope affect reaction time (RT), movement time (MT), block time (BT), average, maximum horizontal/vertical forces (Ave_H_F, Max_H_F, Ave_V_F, Max_V_F)

and horizontal/vertical impulses (H_J, V_J), centre of mass distance to front edge (Dis_CM), angular displacement of centre of mass (Ang_D_CM), and take-off velocity angle (Ang_Vel), take-off horizontal (TO_H_J) and vertical velocity (TO_V_J), 0-5m time (t-5m).

METHOD

Participants

Six male competitive swimmers whose major strokes are butterfly and freestyle participated (Table 1). All swimmers considered as experienced in sprint events with the achievement of approximately 750 FINA points for 50m races. They were informed of the data collection procedures and filled-signed a consent form prior to the study. The consent form was in accordance with the Declaration of Helsinki as amended by the World Medical Association Declaration of Helsinki (World Medical Association, 2013). Ethical Board of Middle East Technical University (28620816/88-139) approved the study.

Data collection and analysis procedure

Participants completed their usual warm-up (approx. 30min) for 50m freestyle or butterfly races, and they experienced the block settings by five to ten repetitions for the familiarization before the trials. Three starts from a block with a 65cm height, and a flat surface (65cm_flat) were performed initially. The swimmers respectively performed the same number of starts from blocks with a 75cm height and a flat surface (75cm_flat), a 65cm height and a 10° sloped surface (65cm_sloped), a 75cm height and a 10° sloped surface (75cm_sloped) on each other day. Undulatory movements were not allowed for the first 5m. Five-minute breaks were given to avoid muscle fatigue after each start. Swimmers used preferred feet placement and body position on the blocks. Analyses were carried out of the best 0-5m timed performances of each block setting.

RT was calculated as the time interval between the starting signal and the first impulse generated by the swimmer. MT was calculated as the time interval between the first impulse after the starting signal and the last impulse before the take-off. Sum of RT and MT was calculated as BT. Ave_H_F and Ave_V_F were the averages, Max_H_F and Max_V_F were the maximum horizontal/vertical force magnitudes (calculated as ground reaction force) generated by the swimmer during movement. H_J and V_J were calculated using force*time formula.

Table 1. Descriptive Statistics and 0-5m Times of Participants.

Participants	Age (year)	B. Weight (kg)	Height (cm)	Best Time (s)		0-5m Times of Selected Trials (s)			
				B.fly	F.style	65cm Flat	75cm Flat	65cm Sloped	75cm Sloped
P1	16.9	84.6	182.6	24.6	23.1	1.91	1.89	1.9	1.89
P2	18.3	86.3	187.6	25.1	23.6	1.92	1.9	1.93	1.89
P3	17.7	81.2	178.3	26.2	23.1	2.03	1.99	2.01	2
P4	18.7	85.4	179.5	24.1	22.9	2.03	1.98	2.01	1.99
P5	16.2	78.3	176.4	24.2	23.2	2.03	2.02	2.02	2.01
P6	19.4	80.1	180.6	24.3	23.3	2.1	2.02	2.02	2
Mean	17.9	82.7	180.8	24.8	23.2				
SD	1.2	3.2	3.9	0.8	0.2				

Modified weighted segmental model by de Leva²⁰ was used to calculate the Centre of Mass (CM) of the swimmers. Dis_CM was the horizontal distance between swimmer's CM and the imaginary perpendicular line originated from starting block's front edge. Dis_CM was measured when the swimmer was at the set position. Ang_D_CM was the total angular change of CM during movement in the sagittal plane. Ang_Vel was the theta angle of the resultant velocity vector at take-off. TO_H_v and TO_V_v were the swimmers' CM vertical and horizontal velocity at take-off, which was calculated using change in the position of CM over the time interval between the take-off and the previous three image frames. Variables related to kinematics were calculated via the 3D motion analysis software (SkillsSpector®, Video4Coach, Denmark). 0-5m times were measured as the time taken from the starting signal for the top of the head to touch a line drawn on the image recorded by the video camera

Kinematic data collection and analysis

Eighteen pre-determined anatomical landmarks (Figure 1) were marked using 2cm diameter circular black stickers. Four high-speed cameras (PlayStation™ Eye, Japan) were connected to a high-performance notebook (Asus, G53SX, Taiwan) to capture the block phase of the start. The camera setup was prepared as in the study of Taladriz, de la Fuente-Caynzos²¹ with distance modifications. The first camera was placed diagonally 2.5m away from the left rear edge of the starting block, and the second camera was placed diagonally 2.5m away from the left front edge of the starting block. The other two cameras were placed on the opposite side of the starting block with the same angulations and distances (Figure 2). Another camera was placed perpendicular to the participant's plane of motion to measure the 0-5m time. Cameras were synchronized, and video clips were recorded at 60fps via the iPi Recorder Software® (iPi Soft, LLC, Russia).

Digitized points were used to build a 3D human models (Figure 3). For the post-processing, 60Hz data was transformed to 100Hz using cubic spline interpolation to match the kinematic and kinetic data in the frequency domain as seen in the study of O'Connor, Thorpe, O'Malley, and Vaughan (2007).

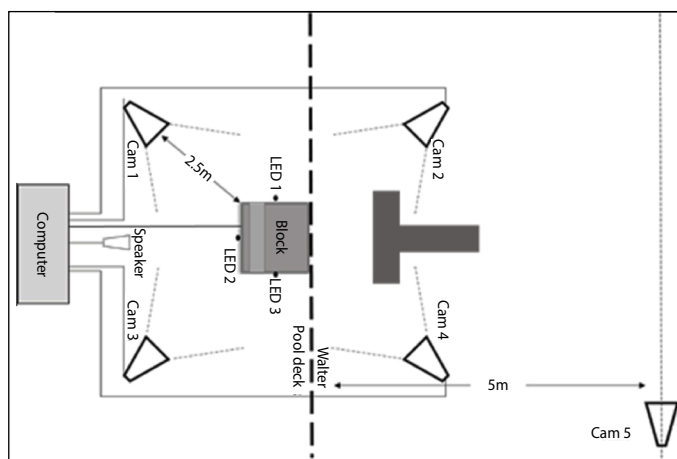


Figure 2. Measurement Setup.

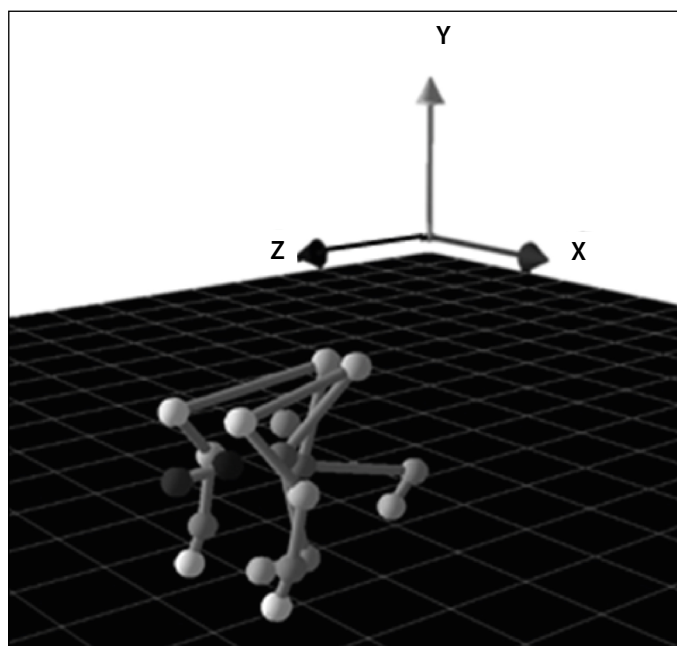


Figure 3. Three-Dimensional Stick Figure of a Swimmer.

Anatomical Landmarks

1. Proximal end of lateral fifth-metatarsal (right-foot)
2. Proximal end of lateral fifth-metatarsal (left-foot)
3. Lateral malleolus of fibula (right-ankle)
4. Lateral malleolus of fibula (left-ankle)
5. Proximal portion of lateral condyle of femur (right-knee)
6. Proximal portion of lateral condyle of femur (left-knee)
7. Lateral greater trochanter (right-hip)
8. Lateral greater trochanter (left-hip)
9. Lateral greater tubercle of humerus (right-shoulder)
10. Lateral greater tubercle of humerus (left-shoulder)
11. Lateral epicondyle (right-elbow)
12. Lateral epicondyle (left-elbow)
13. Center of lateral wrist Joint (right-wrist)
14. Center of lateral wrist joint (left-wrist)
15. Distal end of lateral third phalanx (right-hand)
16. Distal end of lateral third phalanx (left-hand)
17. Frontal bone
18. Frontal end of mandible

Figure 1. Marker Locations.

Kinetic data collection and analysis

An OSB11 replica equipped with four load cells (3 for the vertical axis, 1 for the horizontal axis; NBC Elettronica, Spain) used for all measurements (Figure 4). Ground reaction force (GRF) data were collected at 1000Hz using a NI WLS/ENET-9163 (National Instruments, ABD) wireless carrier with an embedded NI 9237 (National Instruments, ABD) series measurement module. A virtual instrument created in LabVIEW® (Ver. 2012, National Instruments, ABD) software was used for data acquisition and logging procedures. Each swimmer's vertical and horizontal GRFs were normalized to their body weight before analyses and resampled into 100Hz using the same cubic spline interpolation method. The accuracy of the platform was tested with both static and dynamic approaches. For the static vertical test, after the force readings were zeroed, 50-100-150-200kg International Weightlifting Federation certified lifting discs (Eleiko, Sweden) were placed on the platform while the platform's surface was in parallel to the horizontal plane. In order to measure horizontal force, the same discs were hung from the rear end of the platform surface with a 1.5kg steel apparatus while the platform's surface was in parallel to the vertical plane. Loadings were done for 15 times for each weight and each axis. For the dynamic test, an 'S' type load cell (NBC Elettronica, Spain) that connected to DAQ card was pulled with an increased force for 10s (for both axes) One-sample t-tests were used to test whether the mean differences between data obtained from the platform and given input was different than '0'.

Statistical Analyses

Two-way within-subject design ANOVA's were implemented to examine the main and the interaction effects of height and slope. All variables except Ave_H_F and Ave_V_F were analysed with a sample size of six. Ave_H_F and Ave_V_F data were divided into five fractions to investigate the temporal changes in detail. For all tests, the alpha level was set at .05 significance level.

RESULTS

T-test results indicated that the mean differences for all loadings were not different than zero showing the accuracy of the platform is reliable for static and dynamic measurements ($p > .01$)

Analyses showed no significant interaction effect. MT ($p = .009$), and BT ($p = .03$) were shorter for sloped blocks. Max_H_F ($p = .04$), Ave_V_F ($p < .001$), Max_V_F ($p < .001$), and V_J ($p = .001$) were greater for sloped blocks (Figure 5). In a given sample data, it can be seen more resultant force vectors close to the vertical axis were observed in sloped blocks (Figure 4). Fractional analyses indicated that the block slope has a significant effect on the



Figure 4. Replica of the OSB11 Starting Block.

first fraction, and swimmers generated more V_F in this fraction ($p < .01$; Table 2). The main effect of block height was found for t-5m ($p = .005$).

DISCUSSION

Block Height

In our study, we found a significant effect of block height on the 0-5m time. Although pairwise comparisons did not show any significant difference, descriptive statistics demonstrated an increase for time to reach 5m when swimmers dove from the lower (.65m) blocks. After an extensive literature review, we could not find a study examining the relationship between block height and 0-5m performance. Nevertheless, explaining this result may be possible with the simple laws of physics. The higher blocks can provide a longer aerial travelling to swimmers, which result in a lesser water drag resistance for 0-5m, and decrease 0-5m times. However, without measuring the flight distance or flight time, this explanation can be speculative only.

Gehlsen and Wingfield¹⁹ found increments for vertical and resultant velocities upon the water surface for pike and flat grab starts as starting blocks got higher. They didn't give any clear explanation for the velocity increments. Probably the vertical and resultant velocities increased as a result of gravitational forces acting on the swimmers' body mass as the height increased. The fact that platform height has no effect on horizontal velocity was a common finding with our study and theirs.

Cornett, White¹⁵ reported significantly faster head velocities at the maximum head depth for dives from the standard block (.76m) and pool deck (.21m) than dives from the intermediate block (.46m). Unfortunately, they did not give a clear explanation for this non-linear relation and associated their results to the training background of swimmers. Besides, the velocity of the swimmers was measured under the water. Since variables such as drag resistance and lift forces are linked with the underwater velocity, it was not possible to compare their results with ours.

Block Slope

A significant effect of block slope was found for the movement time, which was approximately .05s faster for dives from the sloped blocks. Elliot and Sinclair¹⁶ indicated that block slope did not affect movement time when the grab start was used. Also Stewart¹⁸ stated that regarding power production 10 degrees slope was not advantageous for the grab start. On the other hand, grab start technique is most opposite technique to the kick-start in terms of feet positioning. It seems that unlike the grab start, where the two feet stand side by side, the kick-start technique is affected by the block slope.

Contrary to previous studies²²⁻²⁵ increase of centre of mass distance to the front edge did not increase the movement time in our study. Since these studies investigated the effect of different centre of mass positions using only fixed sloped blocks, there was no possibility to compare our results with theirs in terms of this variable. In our study, swimmers exerted a greater amount of force in both axes; consequently, they left the block quicker when sloped blocks were used.

Even though a significant increase found for maximum horizontal force, the effect of the slope on horizontal impulse and horizontal take-off velocity was not substantial. There were two explanations for these results. First, for the sloped settings, the average horizontal force was not increased enough to make a difference between settings. Second, the movement time was longer for flat settings, that led an increase in horizontal impulse which was pointed out as one of the main predictors of horizontal take-off velocity in studies of Benjanuvatra, Edmunds,²⁶ Slawson, Conway,⁵ Vantorre, Seifert.²⁷

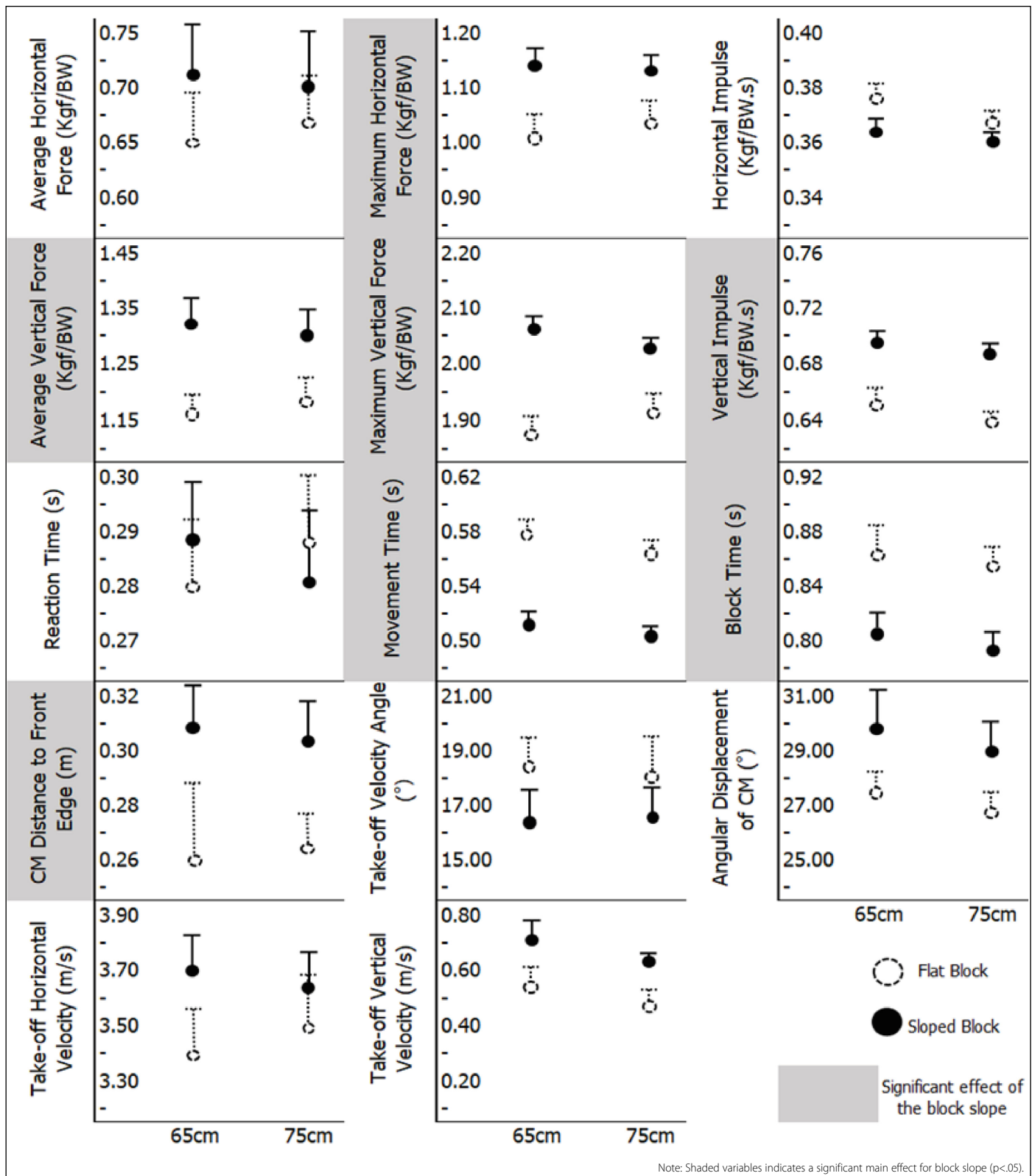


Figure 5. Effects of Block Height and Slope on Kinetic and Kinematic Variables.

Greater vertical force generation on block permits longer flight times, and it is an advantage if a swimmer can use this force to increase the flight distance. In our study, swimmers generated greater average and maximum vertical forces on sloped blocks. Correspondingly, the vertical impulse was greater even though the movement time was shorter for these block settings. The results thus show that the sloped blocks are favourable for swimmers regarding vertical force generation. Nonetheless, one point to consider has emerged with the results of the fractional analyses, which indicated that block slope was most

effective at the first 20% of the block phase regarding vertical force. As stated in the study of Sakai, Koike²⁸ in this duration swimmers exert countervailing vertical forces with both hands and feet to induce pre-tension of muscles for increasing the torque at joints. Considering the position and role of the hands, the forces applied with the legs mostly provide this forward-downward movement. Since take-off horizontal and vertical velocities were higher, downward motion of CM does not necessarily indicate that the sloped blocks have adverse effects on start performance. Swimmers should be aware of this effect of the

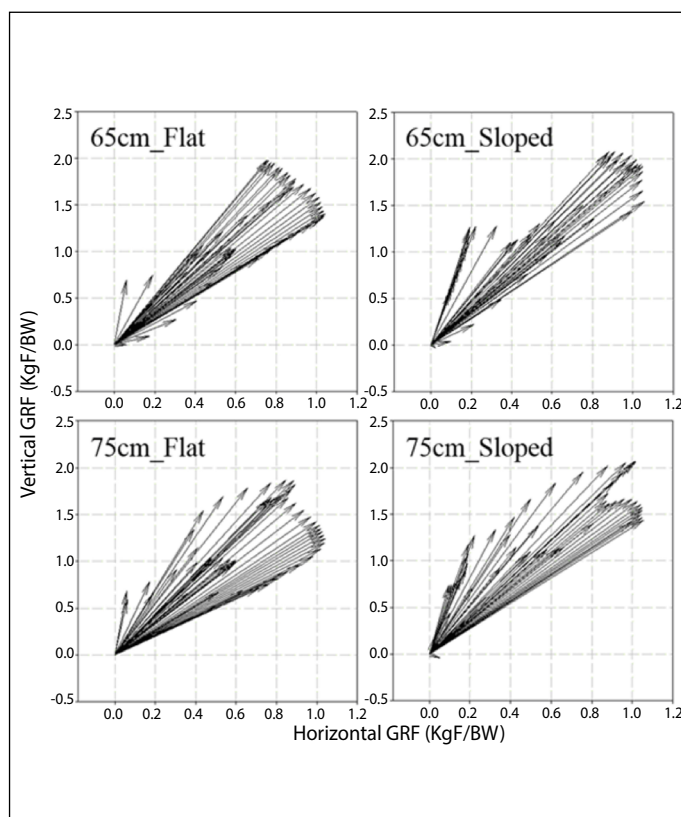


Figure 6. Participant 1's Resultant GRF Vectors for All Block Settings.

Table 2. Main Effects of Block Slope on Vertical Force in 5 Fractions of Block Time (KgF/BW).

Fraction	n	65cm		65cm sloped		75cm		75cm sloped		p
		M	SD	M	SD	M	SD	M	SD	
1 st	6	0.87	0.08	0.99	0.04	0.88	0.11	1.01	0.04	.01*
2 nd	6	1.23	0.23	1.47	9	1.22	0.29	1.45	0.06	0.1
3 rd	6	1.63	0.21	1.8	0.15	1.62	0.17	1.75	0.11	0.14
4 th	6	1.35	0.09	1.64	0.16	1.41	0.28	1.62	0.19	0.51
5 th	6	0.77	0.1	0.85	0.19	0.83	0.2	0.88	16	0.63

sloped blocks and try to generate well-distributed forces during block phase for increasing flight distance, and consider horizontal drive of the body. The intention of repositioning the CM regarding block slope was not clear. Swimmers might lean more forward on the flat blocks because they felt more balanced and safer.

CONCLUSION

Based on our results, blocks with 75cm height and 10° slope can provide favourable block performances to the swimmers. Coaches should know the effects of these blocks on start performance in terms of biomechanics and design their training regimens in accordance.

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