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Ventral swimming starts, changes and recent evolution: A systematic review

Cambios y reciente evolución de las salidas ventrales de natación: revisión sistemática

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Abstract. The purpose of this study was two-fold: to analyse the last changes produced in the swimming starts as a consequence of the implementation of kick-start; and to present topics for future studies and guidance for coaches and swimmers. Fifty studies were reviewed: forty-eight related to the grab start, six focused on the track start and 14 studied the kick-start. Nine additional studies were comparisons between the grab start and track start, six compared the track start and kick-start and just one compared the three start techniques. The outcomes of the studies included in this review showed clear advantages in the kick-start performance with respect to the grab start or track start. The back plate implementation enhanced the force development on the block resulting in larger horizontal take-off velocities and shorter block times. These advantages induced significant improvements in the flight phase with larger distance travelled in less time and shorter time to 5, 10 and 15 m. The use of flexibility training programs as well as lower body strength and power are recommended for an improvement in kick-start technique.
Keywords: Biomechanics, performance, grab start, track start, kick-start.

Resumen. El propósito de esta revisión fue analizar los últimos cambios producidos en las salidas de natación debido a la aparición de un nuevo poyete implementado con un apoyo posterior y presentar temas para futuras investigaciones y una guía para entrenadores y nadadores. Para llevar a cabo dichos objetivos cincuenta estudios fueron revisados de los cuales cuarenta y ocho analizaron la salida de agarre, seis incluyeron la salida de atletismo y 14 la salida de atletismo con apoyo posterior. Además, una comparación entre el rendimiento de la salida de agarre y la salida de atletismo fue llevada a cabo en nueve de los estudios incluidos en esta revisión, seis compararon la salida de atletismo y la salida de atletismo con apoyo posterior y solamente uno incluyó una comparativa entre las tres técnicas. Los resultados de los estudios mostraron claras ventajas en el rendimiento de la salida con los nuevos poyetes con apoyo posterior en comparación a la salida de agarre o la salida de atletismo. La implementación del apoyo posterior incrementó la fuerza generada en el poyete permitiendo obtener una mayor velocidad horizontal en el despegue y un menor tiempo de poyete. Estas ventajas dieron lugar a mejoras en la fase de vuelo (tiempo de vuelo y distancia de vuelo) y en los tiempos de salida a los 5, 10 y 15 m. Para la mejora de la salida de atletismo con apoyo posterior se recomienda a entrenadores y nadadores incluir programas de entrenamiento dirigidos a una mejor aplicación de fuerza en el poyete con apoyo posterior.
Palabras clave: biomecánica, rendimiento, salida de agarre, salida de atletismo, salida de atletismo con apoyo posterior.

Introduction

The swimming start is the first component of a swimming race followed by stroking, turning and finishing (Hay, Guimaraes, & Grimston, 1983). Throughout history, many definitions were used to quantify the swimming start performance. Typically, it is quantitatively measured by the elapsed time between the start signal and the moment when the swimmer's head crosses an imaginary line set at 10 m. (Arellano, Brown, Cappaert, & Nelson, 1994) or 15 m. (Cossor & Mason, 2001; Issurin & Verbitsky, 2002) from the edge of the swimming pool. However, 5 m., 7.5 m., 9 m. or 12 m. were also used as the location to set the finish of the start phase, likewise the swimmer's hip, toe or hands were used as the reference segments (Arellano, Moreno, Martínez, & Oña, 1996; Ayalon, Van Gheluwe, & Kanitz, 1975; Biel, Fischer, & Kibele, 2010; Lee, Huang, & Lee, 2012; Takeda, Takagi, & Tsubakimoto, 2012; Welcher, Richard, Hinrichs, & George, 2008).

The swimming start is considered decisive in the final race result especially in short events. During the World Swimming Championships held in Barcelona (2013), the start time, measured in 15 m, accounted for 24% and 11% of the total time in 50 m and 100 m. events respectively (Argüelles-Cienfuegos & De La Fuente-Caynzos, 2014). The relevance of the start phase on the total swimming race performance gave rise to the development of different start techniques over the years. The most popular techniques in the freestyle, butterfly and breaststroke events are the Grab Start (GS), Track Start and Kick-Start (KS). The GS appeared in the late 1960s and is characterized by a parallel position of the feet in the starting block while the hands grab the front edge of the starting block. The TS appeared in 1973 (Fitzgerald, 1973) but did not gain popularity until the 1990s. This technique is characterized by placing one foot on the front edge of the starting block and the other on the rear part of the starting block. Both techniques (GS and TS) coexisted for more than forty years due to disagreements over their advantages and disadvantages. Several authors did not give priority to the use of one technique over another, concluding that the best start is the one most practiced by the swimmer (Blanksby, Nicholson, & Elliot, 2002; Mason, Alcock, & Fowlie, 2007; Vantorre, Seifert, Fernandes, Vilas-Boas, & Chollet, 2010a). Other investigations gave preference to the TS over the GS (Issurin & Verbitsky, 2002) or vice versa (Krüger, Wick, Hohmann, El-Bahrawi, & Koth, 2003).

The KS appeared in 2009 after FINA (Federation Internationale de Natation) approved the use of a new starting block that features an «adjustable and slanted footrest» (FR.2.7. Starting platforms in FINA's rules). This starting block represented a dramatic improvement in the swimming starts allowing the swimmers a similar starting position than the ones adopted in the TS. However, this technique offers to swimmers the advantage to place their rear foot on a stable and adjustable surface depending of their preferences. Different investigations including the KS were carried out to compare this technique with the TS (Beretiæ, Duroviæ, & Okièiæ, 2012; Nomura, Takeda, & Takagi, 2010; Ozeki, Sakurai, Taguchi, & Takise, 2012), to determine the correct or optimal back plate position or to establish the optimal body position of swimmers on the starting block with a back plate (Honda, Sinclair, Mason, & Pease, 2010, 2012; Ozeki et al., 2012; Slawson, Conway, Cossor, & West, 2012). Despite its recent introduction, researchers found clear advantages of the KS improving the 15 m. time by .14 s. in elite collegiate swimmers (Ozeki et al., 2012).

Currently the KS has been adopted by most of swimmers in international competitions thanks to widespread use of the new starting block with back plate. This fact supposed the decline in GS and TS popularity in last years' competition. The dramatic changes happened in the start techniques in the last years make it necessary to review the current knowledge about this phase of the swimming race. The purpose of the present review was two-fold: to analyse the advantages of the last changes produced in the swimming starts as a consequence of the implementation of KS; and to present topics for future studies and guidance for coaches and swimmers. With this purpose, the discussion of the results is divided into four phases: block phase, flight phase, water phase and swim phase (Cossor & Mason, 2001, Guimaraes & Hay, 1985; Tor, Pease, & Ball, 2014a; Vantorre et al., 2010a).

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Methods

Variables definition

For a detailed biomechanical analysis of the swimming starts several definitions of temporal, kinematic and kinetic variables were used. In order to clarify the information provided in this systematic review, we show a definition of the most commonly variables used in the different studies (Table 1).

Table 1.
Variables definition

VARIABLE	DEFINITION	AUTHORS
Time 5 m (s)	Starting signal--head cross the 5 m	Arellano et al. (2000)
Time 7.5 m (s)	Starting signal--head cross the 7.5 m	Biel et al. (2010)
Time 10 m (s)	Starting signal--head cross the 10 m	Arellano et al. (2000)
Time to 15 m (s)	Start signal--head cross the 15 m	Issurin & Verbitsky (2002); Ozeki et al. (2012); Ruschel et al. (2007); Seifert et al. (2010); Vantorre et al. (2011); Vantorre et al. (2010b); Vantorre et al. (2010); West et al. (2011)
Reaction time (s)	Starting signal--first sensible movement	Barlow et al. (2014); Blanksby et al. (2002); Mason et al. (2007)
Block time (s)	Starting signal--feet separation from platform	Arellano et al. (2000); Beretic et al. (2012); Issurin & Verbitsky (2002); Nomura et al. (2010); Ozeki et al. (2012); Ruschel et al. (2007); Seifert et al. (2007); Seifert et al. (2010); Vantorre et al. (2010b); Vantorre et al. (2010)
	Starting signal--total vertical force fell to zero.	Mason et al. (2007)
Take-off angle (°)	Horizontal/ hip /block edge	Galbraith et al. (2008)
	Horizontal/center mass/block edge	Arellano et al. (2000); Beretic et al. (2012); Nomura et al. (2010); Ozeki et al. (2012); Vantorre et al. (2011)
	Resultant velocity vector/horizontal	Nomura et al. (2010)
	Arms/Trunk and body/horizontal	Vantorre et al. (2010)
	Ankle/hip/horizontal	Seifert et al. (2010)
Horizontal, vertical and resultant take-off velocity (m/s)	Magnitude of the horizontal, vertical and resultant velocity of the CoM vector at take-off	Arellano et al. (2000); Galbraith et al. (2008); Nomura et al. (2010); Ozeki et al. (2012); Mason et al. (2007)
Angular momentum ($kg.m^2/s$)	Product of the momentum of inertia and angular velocity	Vantorre et al. (2011); Vantorre et al. (2010)
Knee angle (°)	Hip/knee/ankle at the set position	Beretic et al. (2012); Nomura et al. (2010)
Ankle angle (°)	Knee/ankle/finger toe at the set position	Beretic et al. (2012); Nomura et al. (2010)
Hip angle (°)	Ankle/hip/shoulder	Seifert et al. (2010)
	CoM legs/hip/shoulder	Vantorre et al. (2011)
Flight time (s)	Take-off--entry hands	Arellano et al. (2000); Beretic et al. (2012); Blanksby et al. (2002); Nomura et al. (2010); Seifert et al. (2010); Vantorre et al. (2010b); Vantorre et al. (2010)
	Take-off--head making contact with the water	Ruschel et al. (2007); Seifert et al. (2007)
Flight distance (m)	Take-off--hands touch the water	Beretic et al. (2012); Blanksby et al. (2002); Galbraith et al. (2008); Nomura et al. (2010); Ozeki et al. (2012); Seifert et al. (2010)
Entry angle (°)	Trunk/Horizontal	Vantorre et al. (2010)
	CM/ horizontal/hands	Beretic et al. (2012); Ozeki et al. (2012)
	Trunk/horizontal/head	Ruschel et al. (2007)
	Wrist/hip/horizontal	Seifert et al. (2010)
	Horizontal/fingertips/hip joint	Barlow et al. (2014)
Angle of attack (°)	Velocity vector CoM/CoM/Hands	Ozeki, Sakurai & Taguchi (2008)

Data Search and Study Selection

Literature searches were performed in the PubMed, Web of Science (WOS), Scopus, and SPORTDiscus databases. We screened for studies that performed a biomechanical analysis of the most popular start techniques used in competition in the last years (GS, TS and/or KS). Consequently, the main search term keyword used was «*Swimming Start*». Moreover, this keyword was combined (using the connectors «AND» «OR») with the terms biomechanics, performance, grab start, track start and kick-start such as the search terms were: «swimming start AND biomechanics», «swimming start AND performance», «swimming start AND (grab start OR track start OR kick-start)».

In addition to the database searches, we also conducted a search of the Proceedings of the ISBS (www.isbs.org), the «International Symposium of Biomechanics in Swimming» and the «International Symposium on Biomechanics and Medicine in Swimming. Additionally, other documentary sources (books or web pages) were checked in order to involve all relevant studies about swimming starts.

The search was made in December 2015 and was restricted based on the publishing year. Only studies from 1st January 2000 to 21st December 2015 were included in this review. The total database searches produced 161 results in the PubMed database, 766 results in the Web of Science database, 375 results in the Scopus database and 367 results in the SPORTDiscus database. Proceedings of international congresses on biomechanics and other documentary sources reported a total of 98 results (Figure 1).

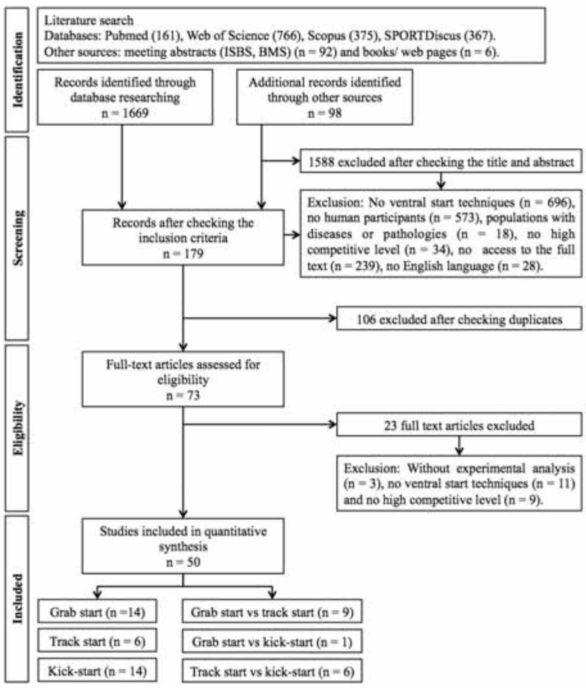

Figure 1.
PRISMA diagram adapted describing the search protocol used in our review (Liberati et al., 2009).

Inclusion criteria

- Papers with an experimental analysis, which reported quantitative results of the analysed variables.
- Studies involved the swimming sport reporting results of ventral start techniques.
- Human participants. All studies including robots or animal species were excluded.
- Studies focused on populations without diseases or pathologies.
- High competitive level of the sample (national, international or elite swimmers). Only studies where was ensure an enough experience in the swimming starts performance for all participants were included in this review.
- References with access to the full text.
- Studies published in the English language.

After finishing the literature search we proceed to dismiss the papers based on the title and abstract as well as the inclusion criteria. Then, a screening based on the repeated results and a detailed reading of the complete article was carried out. Two different reviewers examined the articles retrieved for inclusion in this review. Furthermore, a third reviewer evaluated the articles and determined the inclusion when discrepancies between the first ones reviewers happened. Finally, a total of 50 papers were included in this review. Figure 1 display the diagram of the literature search and the paper selection process.

Results

The literature search disclosed 50 studies, between them, 14 studies included the GS technique, six the TS technique and 14 the KS technique. Moreover, 16 studies reported a comparison between some of these techniques: nine compared TS and GS, six TS and KS and just one compared the three techniques (GS, TS and KS). Table 2 shows a summary of each study including the sample size, the objectives, the start technique and the main results.

Table 2.
Summary of each study included in the review.

Author	Subjects	Start technique	Objective	Main results and conclusions
Arellano et al. (2000)	17 swimmers	Grab Start	To improve the swimmer's starting technique integrating force and video data from all the starting phases.	Negative vertical force before at take-off hands. Progressive increase in horizontal force. Correlation between horizontal force on the block and time to 10 m. (r = -.522). Correlation between resultant velocity at hands entry and time to 5 m. (r = -.56).
Benjanuvatra et al. (2007)	16 females (9 elite, 7 trained)	Grab Start	To identify the key features at take-off and examine the relationships between the start performance and four different jumping (CMJ height, SQJ height, CMJ distance, SQJ distance).	Significantly higher horizontal impulse and shorter time to 5 and 15 m. in the elite swimmers. Negative correlation between time to 5 m. and horizontal impulse for elite swimmers (r = -.701) Lack of relationships between the grab start and jumping performances.
Elipot et al. (2009)	8 swimmers	Grab Start	To determine the swimmers' loss of speed and the factors and the motor coordination influencing this loss of speed during the underwater phase.	The streamlined position should be held until 5.63-6.01 m. to avoid create hydrodynamic resistance. A kinematical synergy of the shoulder, hip and knee joints is determinant for the best streamlined position and to minimize the hydrodynamic resistance.
Elipot et al. (2010)	12 males	Grab Start	To determine the motor coordination produced during the underwater phase.	The best underwater undulatory swimming is dependant on a synergic action of the hip and ankle.
Houel et al. (2010)	12 swimmers	Grab Start	To determine the relevant factors in the underwater phase performance.	The swimmers should maintain the gliding phase until the 5.5 m. distance. An optimal underwater undulatory swimming only depends on the legs and feet propulsion.
Houel et al. (2013)	10 swimmers	Grab Start	To estimate the velocity of the swimmer's CoM and hip during the underwater phase and define the determinant factors in the underwater phase performance.	Swimmer should stay in a streamlined position until to reaches 6 m. The decrease of the angle of attack of the trunk and the foot was related with an improvement in the CoM and hip horizontal velocities. Angles of attack directly influence drag and lift coefficients of the body. During the underwater leg kicking, the swimmer can improve the velocity by increasing kick frequency and maintaining large kick amplitude.
Lee et al. (2001)	5 (4 males, 1 female)	Grab Start	To investigate the pattern of muscle contraction and to compare to the squat jump and countermovement jump.	Different pattern of muscle contraction between grab start, squat jump and countermovement jump. The set posture and the direction of movement made a more complex movement for grab start.
Lee et al. (2002)	8 males	Grab start	To determine the effect of muscular pre-tension strategy.	Muscular-pretension reduces the block time and increases the take-off velocity.
Ruschel et al. (2007)	4 swimmers	Grab Start	To analyse, through kinematic variables the block, flight and underwater phases.	Significant correlation between time to 15 m and flight distance (r = -.482), entry angle (r = .512), maximum depth (r = .515) and underwater velocity (r = -.645).
Seifert et al. (2007)	11 males	Grab Start	To analyse the kinematics and coordination of the breaststroke start.	Significant correlation between time to 15 m and the time in the underwater phase (r = -0.716) and short swim phase (r = .716).
Seifert et al. (2010)	11 males	Grab Start	To analyse the aerial start phase.	Positive correlation between entry distance (r = .38), flight time (r = .36) and block time. Positive correlation between take-off angle (r = 0.61), entry angle (r = .45) and flight time. Positive correlation between entry angle (r = 0.57), height (r = .39) and power developed during the CMJ (r = .40) and take-off angle. Positive correlation between entry angle and hip velocity at water entry (r = .49). Negative correlation between take-off angle (r = -.43), entry angle (r = -.47), entry distance (r = -.36), block time (r = -.51), flight time (r = -.69) and the 15 m. time.
Vantorre et al. (2010)	5 males	Grab Start	To analyse the influence of the angular momentum around the mediolateral axis.	Significantly less rotation generated at take-off induced a flat aerial trajectory allowing enter into the water more quickly. The arm swing increases the quantity of rotation.
Vantorre et al. (2010b)	11 males	Grab Start	To analyse the motor control during front crawl swimming starts of elite and trainer swimmers.	Elite swimmers generated higher values of resultant impulse with similar block time. Consequently, they left the block with high velocities and cover greater distance in less time during the flight phase. The resultant impulse increase with the arm swing. Elite swimmers spent less time in the aerial phase and more time in the underwater phase.
Vantorre et al. (2010c)	15 males	Grab Start	To analyse the influence of the starting actions up to 25 m distance.	Correlation between block time and time to 15 m. (r = -.596). Correlation between flight time (r = -.504), entry time (r = -.436) and time to 15 m. Correlation between underwater time and time to 15 m. (r = .293).
Fischer and Kibele (2014a)	16 males	Track Start	To examine the kinematic differences in elite swimmers	Negative correlation between the hip angle at water entry (r = -.72), horizontal velocity during the underwater phase (r = -.72), the maximal depth (r = -.69) and the time to 7.5 m.
Fischer and Kibele (2014b)	46 (28 males, 18 females)	Track Start	To derive key parameters for the analysis of the entry phase and to identify different movement strategies for the entry phase.	Three patterns were identified at water entry: flat dive, pike dive with a quick deflection and pike dive with a delayed deflection movement. Pike dive with a quick deflection presented larger angle of attack and entry hole as well as an optimal depth (.94 ± .18).
Galbraith et al. (2008)	12 (5 males, 7 females)	Track Start One-handed track start	To compare the track start and one-handed track techniques.	Higher advantages in total to 10 m., horizontal and vertical peak force for the track start. Block time and flight time influenced the time to 10 m. Peak horizontal force of the lower limbs influenced the flight distance and time to 10 m. Vertical take-off velocity influenced the flight distance.
García-Ramos et al. (2015)	21 females	Track Start	To determine the relationship between block phase and the times to 5, 10 and 15 m.	The horizontal take-off velocity and the average horizontal acceleration were the two best predictors of start performance at 5, 10 and 15 m. distance.
Ozeki et al. (2008)	17 males	Track Start	To investigate the effect of different entry methods on the performance of the entry phase.	Negative correlation between time to 15 m. and entry velocity (r = -.543). Positive correlation between time to 15 m. and angle of attack (r = .581).
West et al. (2011)	11 males	Track start	To identify and examine the variables that determine start performance.	Significant correlation between peak power (r = -.85), jump height (r = -.69), relative power (r = -.66), lower body strength (r = -.56) of the land test and time to 15 m.
Barlow et al. (2014)	10 (7 males, 3 females)	Kick-start	To investigate differences and advantages between front, neutral, and rear-weighted kick-start.	Front-weighted kick-start showed shorter movement time, block time than neutral and rear weighted kick-start. Rear-weighted kick-start showed shorter time to 5 and 15 m.
Cossor et al. (2011)	6 males	Kick-start	To determine the relationships between land tests and starting performance.	Positive correlations between the peak forces measured during the land tests and the peak forces on the back and main plate. Greater peak forces measured on land were associated with longer flight distance.
Cuenca-Fernandez et al. (2015)	14 (10 males, 4 females)	Kick-start	To compare the effects of two protocols of post-activation potentiation (PAP) on swim start performance.	A warm-up including a dynamic stretching and a PAP stimulus on the YoYo squat flywheel device with a recovery of 8 minutes before the swim start increases the horizontal take-off velocity and decrease the block time, time to 5 and 15 m.
Honda et al. (2012)	18 (9 males, 9 females)	Kick-start	To determine the performance effects of different back plate positions and starting positions.	A backward position of the back plate produced significantly higher horizontal take-off velocity, resultant and horizontal peak forces but no differences in the block time and times to 5 and 7.5 m. Rear-weighted kick-start showed higher horizontal take-off velocity, flight distance but lower force production and longer time to 5 m. than front-weighted and neutral-weighted kick-start.
Kibele et al. (2014)	14 females	Kick-start	To evaluate the variation of the stance position in the swim start performance.	Forward and higher CoM position on the block with a narrow stance of the back plate and a forward and lower CoM 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.
Kilduff et al. (2011)	9 (7 males, 2 females)	Kick-start	To determine the effects of a PAP stimulus on time to 15 m.	Improvements in lower body power during a countermovement jump after a post-activation potentiation (PAP) and a recovery of 8 minutes. No significant differences in the time to 15 m between a swim start preceded by a specific warm-up and a swim start preceded by a PAP stimulus.
Slawinski et al. (2010)	12 swimmers	Kick-start	To compare the start performance of elite and well trained sprinters.	Positioning the CoM as close as possible to the start line is important in reducing the CoM displacement on the block and in creating a greater CoM velocity during the pushing phase. The maximal acceleration was reached when the rear foot pushed on the rear block, in than .15 s. The rate of force development and the maximal force produced within a given contraction time are important parameters to obtain higher velocity.
Slawson et al. (2011)	32 (17 males, 14 females)	Kick-start	To analyse the effect of different set-up positions and swimmers stance on the start performance.	Narrow stance produces advantages in the block time, horizontal peak force, vertical peak force, horizontal take-off velocity and flight distance compared to the wide stance.
Slawson et al. (2012)	10 males	Kick-start	To explore the effect of rear knee angle on starting performance.	Positive significant correlations between peak force values and the rear knee angle (r = .701- .688). Athletes performed better starts when they adopted a high front knee angle, of 135°-145° and rear knee angle of 75°-85° at set-up.

Table 2.
Summary of each study included in the review.

Author	Subjects	Start technique	Objective	Main results and conclusions
Slawson et al. (2013)	46 (27 males, 19 females)	Kick-start	Provides a methodology for categorising swimming start performance based on peak force production.	Higher average force on the back plate and high horizontal and vertical peak forces are related to a better start performance. Lower average forces on the main and back plate produced shorter block times. Larger take-off velocities are dependent on medium to high vertical peak force off the footrest. Higher average force on the main block and lower average force on the back plate are related with larger entry distances.
Tor et al. (2014a)	14 (11 males, 3 females)	Kick-start	To analyse the influence of three underwater trajectories in the start performance.	Significantly advantages were observed for the males on the block, flight and entry phase except in the vertical take-off velocity and flight time. During the underwater phase the males obtained higher maximum depth, underwater velocity, breakout distance, average velocity and time to 5, 7.5, 10 and 15 m.
Tor et al. (2014b)	52 (29 males, 23 females)	Kick-start	To analyse the kick-start relative to gender and different strokes.	Swimmers should hold their glide at approximately 6.6 m and achieve a maximum depth of approximately - 0.92 m to minimise the velocity lost during the underwater phase.
Tor et al. (2015a)	52 (29 males, 23 females)	Kick-start	To determine which parameters will affect overall start performance the most, using the kick-start technique.	Horizontal take-off velocity account for 81% of the variance in start performance. During the underwater phase, the time to 10 m, time underwater in descent and the time underwater in ascent have been shown to account for 96% of the variance in start time.
Tor et al. (2015b)	16 (11 males, 5 females)	Kick-start	To investigate the effect of the drag in the underwater phase and the changes produced with different depths and speeds.	Total drag increases as speed increases and as the swimmer travels closer to the water surface. An 8%–24% decrease in drag at speeds above 1.9 m/s and .5–1.0 m. below the surface.
Benjanuvatra et al. (2004)	16 (9 males, 7 females)	Grab Start Track Start	To examine differences between grab start and track start and qualitatively the force development strategies.	Significantly lower movement time, block time, horizontal peak force, average vertical force, vertical impulse and vertical and resultant take-off velocity for track start than grab start. Grab start obtained significantly lower average horizontal force. Grab start is characterized by a progressive development of horizontal force. Peak force before at take-off. Track start showed a faster development of horizontal force with two peaks corresponding to the rear foot and the front foot.
Blanksby et al. (2002)	12 (5 males, 7 females)	Grab Start Track Start Handle Start	To compare the grab start, track and handle dive starts.	No significant differences in reaction time, movement time, block time, flight time, flight distance and time to 10 m between grab start and track start. Correlation between movement time (r = .529), block time (r = .580) and time to 10 m. Correlation between reaction time (r = -.582), movement time (r = .712) and block time. Correlation between flight distance (r = .882), CoM position (r = -.709) and flight time.
Issurin & Verbitsky (2002)	303 (152 males, 151 females)	Grab Start Track Start	To compare grab start and track start.	Significantly shorter block time for track start than grab start ($p < .05$). Time to 15 m. tends to be similar between both techniques. Positive correlation between block time and time to 15 m. The variability of the time to 15 m. for 21-50% is explained by variability of block time.
Krüger et al. (2003)	6 females	Grab Start Track Start	To compare the grab start and track start.	Significantly shorter time to 7.5 m. for grab start. Similar curves of the horizontal and resultant force. Higher impulse between take-off hand and take-off for grab start. And, higher acceleration and take-off velocity.
Mason et al. (2007)	6 swimmers	Grab Start Track Start	To investigate the on block characteristics of the grab start and track start.	Lower movement time, block time and peak power for track start than grab start. Track start shows bimodal curve power. The rear foot generated the greatest peak values. Grab start shows the peak power closer at take-off.
Takeda & Nomura, (2006)	12 swimmers	Grab Start Track Start	To explain the kinematic differences between grab start and track start	Significantly shorter block time for track start. No significant differences in the horizontal take-off velocity. Track start showed a great contribution of rotational component by the rear foot and led a lower angular displacement of the body angle.
Vantorre et al. (2010a)	7 males	Grab Start Track Start	To compare the performance between preferential and non-preferential techniques and its variability.	Positive correlation between block time and time to 15 m. (r = .31) Positive correlation between flight time and time to 15 m. (r = .31) Positive correlation between entry time and time to 15 m. (r = .43)
Vantorre et al. (2011)	5 males	Grab Start Track Start	To analyse the influence of start preference on the aerial phase.	Track start showed lower vertical impulse and higher centre of mass angular momentum and angular momentum for the legs than grab start.
Vilas-Boas et al. (2003)		Grab Start Track Start	To compare two variants of the track start technique with the grab start.	Significantly higher impulse time, block time, entry time, horizontal, vertical and resultant impulses, horizontal take-off velocity and the total displacement for rear track start than for front track start.
Beretic et al. (2012)	27 swimmers	Track Start Kick-start	To determine the effects of the kick-start on performance relative to the track start.	Kick-start showed significantly lower rear knee angle and rear ankle angle, block time, flight time and time to 10 m than the track start.
Beretic et al. (2013)	27 males	Track Start Kick-start	To examine lower body muscle force characteristics and create prediction model to improve the start performance.	Correlation between maximum voluntary force (r = -.559), leg extensors specific level of rate of force development (r = -.338), leg extensors relative values of maximum muscle voluntary force (r = -.727), leg extensors relative value of specific rate of force development (r = -.402) and time at 10m. The best model to predict time to 10 m. included maximum voluntary force, specific rate of force development, relative voluntary force and relative specific rate of force development.
Garcia-Hermoso et al. (2013)	1657 swimmers	Track Start Kick-start	To investigate the association between block time and final performance.	Significantly shorter block time was observed for men that for women. Swimmers had shorter block time with the starting block with back plate. Block time was related with the final performance in the men's 50 m. event with the old platform and in the women's 100 m. event with the starting block with back plate.
Honda et al. (2010)	14 (9 males, 5 females)	Track Start Kick-start	To compare the kick-start relative to the track start.	Kick-start shows a shorter block time, time to 5 and 7.5 m. Significantly larger horizontal take-off velocity and average horizontal force for the kick-start.
Nomura et al. (2010)	10 males	Track Start Kick-start	To identify the advantages of the back plate on swimming starting.	Significantly smaller values in the horizontal and vertical CoM position, rear ankle angle, horizontal and vertical acceleration before at take-off, take-off angle and vertical take-off velocity for track start. Significantly larger values in the front and rear knee angle and front ankle angle for track start.
Ozeki et al. (2012)	11 males	Track Start Kick-start	To compare the track start and kick-start performance.	Kick-start showed significantly higher horizontal take-off velocity and shorter block time and time to 15 m.
Biel et al. (2010)	7 males	Grab Start Track Start Kick-start	To compare the kinematic take-off from the new starting block and from the traditional starting block.	Kick start obtained shorter block time, higher horizontal velocity and shorter time to 7.5 m. than track start and grab start.

Discussion

The purpose of this study was to analyse the last changes produced in the swimming starts as a consequence of the implementation of KS. With this objective, 50 studies analysing the GS, TS and/or KS techniques were reviewed. The outcomes of the studies included in this review showed important temporal advantages on the block and larger horizontal, vertical and resultant take-off velocity for KS. This is because as a consequence of the asymmetrical position and the back plate implementation swimmers are able to enhance the force developed on the block without increasing the block time. These advantages lead to a dramatic improvement of .14 s. on total start performance (time to 15 m.) relative to the TS and significant advantages at 7.5 m. distance than GS.

Block phase

Block phase performance

The block phase is defined as the time elapsed between the starting signal and the instant the swimmer's feet leave the starting block. The time percentage contribution of this phase was shown corresponding to an 11% of the total start performance (15 m) (Tor et al., 2014a). Previous studies agreement that block phase is not the most critical aspect of an overall start performance. However, the swimmer's motion on leaving the block will influence in the performance of later phases (Mason et al., 2007). Furthermore, Issurin & Verbitsky (2002) reported that a 21-50% of the variability at 15 m. time was consequence of the variability in the block time. Consequently, to optimise and to define the best motion on leaving the block was the goal of the most of studies including different start techniques.

The block phase performance is highly dependent on the type of start technique. The main differences between the GS, TS and KS were found in the forces applied on the starting block. The asymmetrical techniques (TS and KS) were characterized by a bimodal force profile corresponding to rear foot and front foot. In contrast, the GS technique showed a single peak force before at take-off (Benjanuvatra, Lyttle, Blanksby, & Larkin, 2004; Mason et al., 2007). As a consequence of pushing the block with both legs together, the GS showed significantly larger horizontal and resultant peak forces, significantly higher peak power, average vertical force and vertical impulse. Likewise, slightly higher vertical peak force, average resultant force and horizontal impulse values were observed for GS than TS (Benjanuvatra et al., 2004; Krüger et al., 2003; Mason et al., 2007; Vantorre, Seifert, Fernandes, VilasBoas, & Chollet, 2010c). In contrast, significantly smaller average horizontal force values were found for GS than for TS (Appendix; Table 2) (Benjanuvatra et al., 2004; Takeda & Nomura, 2006; Vantorre et al., 2010). This disadvantage was associated with the negative horizontal force values obtained for GS before at take-off hands, whereas the start techniques with an asymmetrical position show a progressive horizontal force development along the block phase (Arellano et al., 2000).

The back plate implementation supposed an improvement in the asymmetrical techniques by an increase of the forces developed on the block. The rear foot support increased the stability of the swimmers on the block and the capacity to develop larger forces with the rear leg. In this regard, different studies showed significant larger values in the horizontal peak force and the average horizontal force for KS than for TS, with differences of .04 BW and .03 BW, respectively (Appendix, Table 2) (Honda, Sinclair, Mason, & Pease, 2010). Unfortunately, a kinetic comparison between the GS and KS was not carried out yet.

The force development on the block plays an important role on the total block phase performance and the total start performance. Several studies reported significant correlations between the average horizontal acceleration, horizontal impulse, peak vertical force, peak power, average horizontal force and the time to 5, 10 or 15 m. Concerning to this, average horizontal acceleration was related to time to 5 (r = -.71), 10 (r = -.65) and 15 m. (r = -.58) (García-Ramos et al., 2015); horizontal impulse was associated with time to 5 (r = -.701) and 10 m. (r = -.52) (Benjanuvatra, Edmunds, & Blanksby, 2007); peak vertical force was associated with time to 10 m. (r = -.522) (Arellano, Pardillo, De La Fuente, & García, 2000); peak power was related to time to 15 m. (r = -.85) (West, Owen, Cunningham, Cook, & Kilduf, 2011) and the average horizontal force was associated with time to 5 m. (r = -.58), 10 m (r = -.70) and 15 m. (r = -.62) (García-Ramos et al., 2015).

Furthermore, the horizontal force development on the block has high influence on the horizontal take-off velocity, which was considered the best predictor of the start performance. Mason et al. (2007) after analyzing the differences between GS and TS indicated that the horizontal take-off velocity is a good predictor of the starting ability when the take-off angle is also considered. Later, a recent study, which analyzed the key parameters associated with the overall start performance for KS technique, indicated the horizontal take-off velocity to account for 81% of the variance in the total start performance (Tor et al., 2015b).

In the start techniques, larger horizontal take-off velocity permits to swimmers to travel greater flight distance in less time and to enter into the water faster leaving shorter time to 5, 10 and 15 m. (García-Ramos et al., 2015; Nomura et al., 2010; Vantorre et al., 2010b). The largest horizontal take-off velocity values are dependent on the highest impulse developed on the block that is determined by the force developed and the block time. Consequently, studies comparing the GS and TS highlighted the relevance to find an optimal balance between to spend long time on the block to create more force and a short block time to minimize the time deficit (Vantorre et al., 2010b; Vantorre et al., 2010c).

Studies analyzing the differences between the TS and GS showed similar horizontal take-off velocities between both techniques. In spite of the TS developed larger average horizontal force, the GS, as a consequence of larger horizontal peak force and longer block time, compensated the negative values of horizontal force obtained before at take-off hands achieving similar horizontal take-off velocity values than in TS (Benjanuvatra et al., 2004; Krüger et al., 2003; Takeda & Nomura, 2006). Unlike all previous studies, the implementation of the back plate allowed block time to be reduced without sacrificing horizontal impulse (Honda et al., 2010). The block time obtained significant smaller values for KS than for TS (Beretiæ et al., 2012; Garcia-Hermoso et al., 2013; Honda et al., 2010; Ozeki et al., 2012) and it was significantly reduced in comparison with GS (Biel et al., 2010). Moreover, higher horizontal take-off velocity was obtained for KS than for GS and TS with differences ranged from .07 to .12 m/s. (Appendix, Table 1) (Biel et al., 2010; Honda et al., 2010; Ozeki et al., 2012).

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 (Biel et al., 2010; Honda et al., 2010; Ozeki et al., 2012). Nomura et al. (2010) showed larger acceleration values 0.3 s just before the take-off for KS than for TS, with differences of .80 m/s^2 and -.42 m/s^2 for horizontal and vertical component, respectively. Furthermore, Slawinski et al. (2010) observed the peak of acceleration when the rear foot pushed on the back plate, in less than .15 s. Consequently, swimmers are able to obtain larger temporal advantages before at take-off of the rear foot as well as higher horizontal force which let shorter block time and larger horizontal take-off velocity values. Later studies related the ability to produce force quickly with the time to 10 m. and the lower body strength and power with the time to 15 m. (Beretiæ, Durovic, Okicic, & Dopsaj, 2013).

Back plate and centre of mass position on the block for KS technique

The great advantages provided by the back plate and the different configurations of this mobile surface (five different positions) has led some studies to focus their investigations on the optimal back plate position (narrow, preferred or wide stance) (Honda et al., 2012). Moreover, most other studies measured different centre of mass positions (CoM) on the block to provide differences in the KS performance. These studies analysing three different variants: Neutral-weighted Kick-Start (NKS) characterized by a neutral projection of the swimmer's CoM, the Rear-weighted Kick-Start (RKS) with a rear projection of the swimmer's CoM and the Front-weighted Kick-Start (FKS), which exhibits a front projection of CoM in the set position (Barlow, Halaki, Stuelcken, Greene, & Sinclair, 2014; Honda et al., 2012; Kibele, Biel, & Fischer, 2014; Slawinski et al., 2010).

The results of these studies differed in the biomechanical advantages observed for the different back plate configurations and CoM positions on the block. Relative to the back plate position, a wide stance of the back plate, those positions further from the edge of the block, was suggested to be optimal to obtain higher horizontal take-off velocity and shorter block time. A narrow stance, those positions closer to the edge of the block, allowed to develop greater horizontal and resultant peak forces with the rear leg (Honda et al., 2012). In contrast, Kibele et al. (2014) showed larger advantages in the block time and horizontal peak force with a narrow stance. Similar contradictions were found relative to the CoM position on the block, Slawinski et al. (2010) indicated that a CoM position closer to the start line (FKS) is important in reducing the displacement of the CoM on the block as well as in creating a higher horizontal take-off velocity and shorter block time. However, later studies showed lower block time, horizontal take-off velocity and flight distance as well as longer time to 5 and 15 m. in FKS than in RKS (Kibele et al., 2014).

In agreement with Slawinski et al. (2010) and Seifert et al. (2012), the contradictions in the results of the different back plate configurations and CoM positions could associate to changes in the knee angle. The knee angle is an important parameter in the block performance because is directly related with the force production at the starting signal (Slawson et al., 2012; Slawson, Conway, Cossor, Chakravorti, & West, 2013). In this regard, for KS a rear knee angle approximately at 75-85° and a front knee angle at 135-145° at set-position was shown the most effective angles for a shorter time on the block and higher horizontal take-off velocity (Slawson et al., 2012, 2013). In this line, Slawson et al. (2012) found that swimmers adjusted their body position to accommodate the movement to the different back plate stances obtaining the same knee angle values. Likewise, Slawinski et al. (2010) associated the forward CoM position with a greater rear knee angle. In this regard, a greater rear knee angle was shown to allow a position of the shoulder further forward and to move the CoM closer to the start position. As a conclusion, the optimal back plate position and the CoM position on the block seems to be one that allows swimmers to adopt an optimal knee angle.

Flight phase

The flight phase is the time elapsed between the instant the swimmer's feet leave the starting block and the swimmer's first contact with the water surface. An early study established the time percentage contribution of each phase of the start (15 m.) reporting a 5% for this phase (Tor et al., 2014a). The flight phase performance is highly influenced by the block phase. Furthermore, its small contribution in the overall start performance led to few studies including an analysis of this phase. The most commonly parameters used for a biomechanical analysis of the flight phase are the flight time, flight distance and entry angle. Flight time and flight distance were associated with the take-off angle (r = -.59 and r = .88- .67, respectively) (Arellano, Garcia, Gavilán, & Pardillo, 1996; Detanico, Heidorn, Dal Pupo, Diefenthaeler, & dos Santos, 2011) and the block time (r = .36) (Nomura et al., 2010; Vantorre et al., 2010b). Moreover, the entry angle was significantly related with the take-off angle (r = .57) (Seifert et al., 2010).

The horizontal take-off velocity was also shown an important parameter for the flight phase performance. In agreement with early studies, the highest horizontal take-off velocity allows swimmers to cover greater distances in less time during the flight (Vantorre et al., 2010b). In this regard, the similar results in the flight time and flight distance between GS and TS were related with the similarities in the horizontal take-off velocity (Blanksby et al., 2002; Takeda & Nomura, 2006; Vantorre et al., 2010c). On the contrary, the largest horizontal take-off velocity values reported for KS than for TS led to significant temporal advantages but similar distances travelled for the first one (Beretiæ et al., 2012; Nomura et al., 2010; Ozeki et al., 2012). Unfortunately, nowadays no study reported differences related to the flight phase between the GS and KS. However, the largest horizontal take-off velocity showed for KS than for GS (Biel et al., 2010) suggests that the KS obtains similar advantages for GS than the ones showed for TS along the flight.

Besides the flight time and flight distance, the swimmers' body rotation during the flight phase is considered an important parameter in the study of swimming starts. This is because is a determinant factor on the water entry (Vantorre et al., 2010; Vantorre et al., 2011). The body rotation depends on the angular momentum produced at take-off. In this regard, larger angular momentum values at take-off will permit to swimmers larger rotational movement along the flight and larger entry angles (Vantorre et al., 2010). In spite of the relevance of the body rotation in swimming starts, currently only one study measured the angular momentum between the GS and TS (Vantorre et al., 2011). The results presented by Vantorre et al. (2011) revealed a larger displacement of the lower limbs in TS as a consequence of significantly larger angular momentum for the legs as well as larger CoM angular momentum at take-off obtained for TS than for GS. However, the impact of these differences on the water entry was not measured. As a consequence of the relevance of the angular momentum and the body rotation on the water entry, a further analysis including this parameter would be required to observe the differences and the advantages provided to each start technique.

At water entry, the entry angle and hip angle were shown relevant factors for the start performance as a consequence of the impact on the water phase. The entry angle was shown to have influence on the depth of the gliding phase and consequently on the drag force and the average velocity of the water phase (Elipot et al., 2009). The studies that included this variable to compare the KS and TS or the GS and TS showed similar results between them (Beretiæ et al., 2012; Ozeki et al., 2012; Vantorre et al., 2011). In this regard, the back plate and the asymmetrical position seems to not affect the water entry suggesting that all techniques will obtain similar performance on the subsequent phase (gliding phase). Concerning the hip angle, recently Fischer and Kibele (2010) after examining the kinematic differences relative to the entry behaviour of sixteen male elite swimmers in the TS technique found a strong relationship between the hip angle and the starting performance (measured by the time to 7.5 m.) (r = -.72). The largest hip angles at water entry seemed to minimize the loss in horizontal velocity by the use of a dolphin-kick after the feet immersion. It was shown that larger angle of attack as well as a large entry hole are required to get largest hip angles (Fischer & Kibele, 2014). However, no study comparing the GS, TS and KS included the hip angle, angle of attack or the entry hole.

Water phase

The water phase is defined as the time elapsed between the first contact with the water and the swimmers' head re-surfacing. To improve the analysis of the starts, the water phase was divided into two sub-phases: the glide phase defined as the time elapsed between the first contact with the water and the start of the swimming movement; and, the underwater leg propulsion phase defined as the time spent between the first kick and the first stroke (Elipot et al., 2009). The water phase is considered the most important in the start performance because is the longest relative to the block or flight phase (time percentage contribution, 56%), the fastest phase below the water (Elipot et al., 2009; Tor et al., 2014a) and also because it explain the greatest proportion in the variance of the 15 m start time. However, it is important to note that the performance of the water phase is affected to some extent by the resulting parameters of the previous phases although the actions performed during the gliding or underwater leg propulsion are not dependent on the type of swimming starting technique (Mason et al., 2007). Consequently, the goal of the most of studies including start techniques was to examine the characteristics required to maintain the advantages obtained on previous phases along the water phase and to obtain the best total start performance without take to account the type of start technique (Elipot, Dietrich, Heilard, & Houel, 2010; Elipot et al., 2009; Houel, Elipot, André, & Hellard, 2013; Houel, Elipot, Andrée, & Hellard, 2010; Tor, Pease, & Ball, 2014b, 2015a).

The main objective during the water phase was shown to reduce the drag force acting on the swimmers with the objective to avoid an excessive loss of velocity (Cossor, Slawson, Shillabeer, Conway, & West, 2011; Tor et al., 2014b, 2015b). With this purpose, it was suggested that the swimmers should: 1) to get to travel between .50 and .92 m. deep for as long as possible with velocities below above 1.9 m/s. (Elipot et al., 2009; Houel et al., 2013; Houel et al., 2010; Tor et al., 2015a); 2) to maintain the velocities created during the impulsion and aerial phase as long as possible (Elipot et al., 2010). With this purpose, it was indicated that the swimmers should to keep the best streamline position during the gliding phase by an optimal combined action of the shoulder, hip and knee to minimize the hydrodynamic resistance (Elipot et al., 2009; Houel et al., 2013; Houel et al., 2010); 3) to keep the gliding phase until the 5.5 m. and 6.6 m. (Elipot et al., 2009; Seifert, Vantorre, & Chollet, 2007); and, 4) to produce high propulsive force during the underwater kicking through an optimal action of the hip and ankle that permits to increase the leg amplitude with not affect the drag (Elipot et al., 2010; Elipot et al., 2009; Ruschel, Araujo, Pereira, & Roesler, 2007).

The most commonly parameters used to compare the water phase of different start techniques included parameters related to the start performance (time to 5, 7.5, 10 or 15 m). Concerning to this, imperceptible differences were shown when the swimmers reached 5, 7.5 and 15

m. distance between the GS and TS (Benjanuvatra et al., 2004; Mason et al., 2007; Vantorre et al., 2010a). However, temporal advantages of .04, .15 and .14 s. were reported in the 5, 10 and 15 m. time, respectively, for the KS compared to the TS (Beretiæ et al., 2012; Honda et al., 2010; Ozeki et al., 2012). Moreover, significant advantages for KS were also observed in the 7.5 m time relative to the GS (Biel et al., 2010).

Swim phase

The swim phase is the time following the water phase, defined as the interval from head resurfaces until the centre of the head reached the 15 m. mark (Cossor & Mason, 2001). The time percentage contribution of this phase was shown corresponding to an 28% of the total start performance (15 m. time) (Tor et al., 2014a). However, to our best knowledge no study included the swim phase for the analysis of the swim starts. This is because previous studies revealed positive correlation between the swim phase and the time to 15 m. for trainer and national swimmers (r = .716 and r = .673, respectively). In this regard, shorter swim phases seem to be more property to the best start performance. Similar conclusions were supported by Cossor & Mason (2001). These authors found negative correlation between the distance of the underwater phase and the 15 m. time (r = -.942- (-.646)).

Conclusions

The results of the studies included in this systematic review demonstrated that the KS is a superior technique due to the larger application of force on the block, mainly when the rear foot is pushing the back plate, and the shortest block time. As a consequence of the increase of the force developed on the block and the reduction on the time invested on the block, KS obtains larger horizontal take-off velocity which suppose a decrease in the flight time and similar flight distances relative to older techniques (GS or TS). These advantages and the similarities observed between the GS, TS and KS at water entry let to important advantages in the KS performance, with shorter time to 5, 7.5, 10 and 15 m.

Practical applications for coach and swimmers

Based on the results of the different studies, three objectives can be carried out for the improvement of kick-start technique: 1) to increase the development of force on the block in a shorter time (i.e. explosive force). With this purpose Slawinski et al. (2010) recommended a resistance training program with different practical methods, a power training, power and strength training followed by speed training and speed training methods. Likewise, although vertical jumps performance (Squat Jump and Counter Movement Jump) were shown not directly transferred to the grab start performance (Benjanuvatra et al., 2007; Lee, Huang, Lin, & Lee, 2002; Lee, Huang, Wang, & Lin, 2001) for asymmetrical techniques, the 15 m time was related with Counter Movement Jump height and relative power (West et al., 2011). These results emphasized the use of training programs designed to improve the lower body strength and power. Moreover, to include a post-activation potentiation protocol (PAP) with an adequate recovery in the warm-up was shown to improve the lower body power (Kilduff et al., 2011). Concerning to this, a recent study showed that PAP induces significantly improves in peak forces (Cuenca-Fernandez, Lopez-Contreras, & Arellano, 2015). In agreement with these authors, a warm-up including a dynamic stretching followed by the PAP stimulus of four maximal repetitions on the YoYo squat flywheel device eight minutes before the swim race increase the horizontal take-off velocity and decrease the block time, time to 5 and 15 m. of the KS technique; 2) to invest time in a technical training with the aim to determine the best starting position; based on the study of Slawson et al. (2012, 2013), to adopt an optimal set position that permits a front and rear knee angle approximately at 135-145° and 75-85°, respectively, is a key factor for quickest block time and horizontal take-off velocity. Consequently, coach and swimmers should to invest time determining the best back plate position and CoM position on the block with the objective to reach an optimal knee angle. A biomechanics specialist is also recommended to determine the best swimmer's body position on the block. Moreover, a flexibility training of the hamstring was recommended to facilitate the use of these angles; and, 3) to improve the water entry and water phase. At water entry, an increase in the angle of attack and the hip angle was shown essential to minimize the loss in horizontal velocity by the use of a dolphin-kick after the feet immersion (Fischer & Kibele, 2010). Moreover, to increase the power kicking during the underwater leg kicking phase, the amplitude and frequency was also shown relevant to improve the water phase (Elipot et al., 2010; Elipot et al., 2009; Ruschel, Araujo, Pereira, & Roesler, 2007). With these objectives, flexibility training and a strength training were recommended with the objective to reach an hyperextended hip position at water entry and to develop a power dolphin-kick after the feet immersion, to get an optimal action of the hip and ankle during the leg kicking phase and to increase the power kicking.

Future directions

In spite of the recent appearance of the KS technique, the advantages in respect to older techniques (GS or TS) are convincing. However, many questions and contradictory results were found in the studies including this technique. Concerning to this, future studies will be interesting to improve the kick-start technique and the best understanding of its performance:

- The main advantages observed for KS in respect to the TS were associated with the force developed on the block. As a consequence of the back plate implementation, the KS allows to swimmers larger force developed on the block reducing the block time. However, kinetic comparison between the KS and GS were not carry out yet. In this sense, studies comparing both techniques seem to be required with the objective to determine the differences and advantages for KS.
- For KS, 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.
- During the flight phase, the body rotation was shown a determinant factor for the start performance because its influence on the water performance. Several studies including the angular momentum were performed comparing the GS and TS. However, to our best knowledge this variable was not measured for the KS technique. Consequently, studies including the angular momentum and body rotation for KS seem to be required with the objective to analyse its influence in the water entry and water phase.
- At entry into the water, the hip angle was also determined an important parameter for an optimal start performance. This is because larger hip angles at water entry were associated to lower loss in horizontal velocity by the use of a dolphin-kick after the feet immersion. Moreover, hip angle was shown influenced by the angle of attack and the entry hole. In spite of the relevance of this parameter, few studies included this parameter in their analysis. Furthermore, to our knowledge no study analysing the KS technique included these variables. Concerning to this, an analysis about the entry into the water for KS technique is required including the hip angle, angle of attack and entry hole.

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Appendix

Table 1.
Mean and standard deviation values of the biomechanical variables on the block obtained comparing the grab start, track start and kick-start techniques.

	Start Technique	BT (s)	Vx (m/s)	Vy (m/s)	Vr (m/s)	Ax (m/s²)	Ay (m/s²)
Krüger et al (2003)	Grab Start	.91 ± .14					
	Track Start	.91 ± .10					
Benjanuvatra et al. (2004)	Grab Start	.94 ± .04*	4.23 ± .51	3.04 ± .86*	5.27 ± .61*		
	Track Start	.89 ± .07*	4.19 ± .37	2.07 ± .75*	4.72 ± .52*		
Takeda et al. (2006)	Grab Start	.78 ± .03*			4.38 ± .13		
	Track Start	.71*			4.26		
Vantorre et al. (2010a)	Grab Start	.98 ± .09					
	Track Start	.89 ± .07					
Beretic et al. (2012)	Track Start	.76 ± .05*					
	Kick-Start	.73 ± .04*					
Honda et al. (2010)	Track Start	.80 ± .01*	4.41 ± .03*				
	Kick-Start	.77 ± .01*	4.48 ± .04 *				
Nomura et al. (2010)	Track Start	.78 ± .03	4.38 ± .22	-.81 ± .45*	4.47 ± .30	7.96 ± .79*	-.58 ± .79*
	Kick-Start	.76 ± .04	4.34 ± .26	-.65 ± .45*	4.41 ± .32	8.76 ± .87*	.16 ± 1.13*
Ozeki et al. (2012)	Track Start	.74 ± .04*	4.29 ± .12*		4.48 ± .18*		
	Kick-Start	.70 ± .04*	4.41 ± .18*		4.58 ± .26*		

*Significant differences (p <0.05)
Note: BT: Block Time; Vx: Horizontal Take-off Velocity; Vy: Vertical Take-off velocity; Vr: Resultant Take-off Velocity; Ax: Horizontal Acceleration during 0.3 s before the take-off; Ay: Vertical Acceleration during 0.3 s before the take-off.

Table 1.
Continued

	Start Technique	Fx peak (N)	Fx (N)	Fy (N)	Ix (N.s)	Iy (N.s)
Benjanuvatra et al. (2004)	Grab Start	925.43 ± 238.28*	397.64 ± 108.90*	984.60 ±176.05*	308.51 ± 84.08	765.06 ± 146.06*
	Track Start	699.22 ± 136.10*	428.68 ± 103.23*	919.11 ± 194.50*	304.51 ± 75.60	655.15 ± 151.94*
Vantorre et al. (2010a)	Grab Start				210.4 ± 28.6	937.2 ± 138.1*
	Track Start				218.4 ± 24.5	835.8 ± 87.8
Honda et al. (2010)	Track Start	1.09 ± .04 BW	.57 ± .01* BW			
	Kick-Start	1.13 ± .04 BW	.60 ± .01* BW			

*Significant differences (p <0.05)
Note: Fx peak: Peak Horizontal Force; Fx: Average Horizontal Force; Fy: Average Vertical Force; Ix: Horizontal Impulse; Iy: Vertical Impulse.

Table 2.
Mean and standard deviation for the biomechanical variables during the flight phase obtained comparing grab start, track start and kick-start techniques.

	Start Technique	Flight time (s)	Flight distance (m)	Entry angle (°)
Krüger et al. (2003)	Grab Start	.33 ± .05		
	Track Start	.34 ± .08		
Takeda et al. (2006)	Grab Start		3.25 ± .20	
	Track Start		3.15	
Vantorre et al. (2010a)	Grab Start	.29 ± .05		
	Track Start	.30 ± .05		
Beretic et al. (2012)	Track Start	1.07 ± .06*	2.41 ± .15	42.41 ± 3.24
	Kick-Start	1.02 ± .07*	2.37 ± .15	42.22 ± 5.66
Nomura et al. (2010)	Track Start		3.00 ± .19	
	Kick-Start		2.99 ± .18	
Ozeki et al. (2012)	Track Start		2.69 ± .23	39.3 ± 2.2
	Kick-Start		2.69 ± .20	38.5 ± 2.4

*Significant differences (p <0.05)

Table 3.
Mean and standard deviation for the biomechanical variables during the water phase obtained comparing grab start, track start and kick-start techniques.

	Start Technique	Time to 5 m (s)	Time to 7.5 m (s)	Time to 10 m (s)	Time to 15 m (s)
Krüger et al. (2003)	Grab Start		3.36 ± .21*		
	Track Start		3.56 ± .35*		
Vantorre et al. (2010a)	Grab Start				6.5 ± .3
	Track Start				6.6 ± .3
Beretic et al. (2012)	Track Start			3.99 ± 3.84*	
	Kick-Start			3.84 ± .27*	
Honda et al. (2010)	Track Start	1.66 ± .01*	2.73 ± .02		
	Kick-Start	1.62 ± .01*	2.69 ± .02		
Ozeki et al. (2012)	Track Start				6.92 ± .34*
	Kick-Start				6.78 ± .33*

*Significant differences (p <0.05)

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