FORCE DEVELOPMENT PROFILE OF THE LOWER LIMBS IN THE GRAB AND TRACK START IN SWIMMING

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Left and right ground reaction forces of 9 male and 7 female national and international level swimmers were measured during grab and track starts. Analysis of temporal, kinetic and velocity measures indicated that while swimmers left the block faster in the track start, grab starts enabled swimmers to generate greater vertical impulses and take-off velocities. No significant differences were found in the horizontal impulses and the time to 6m between the two starts. Left and right force profiles were examined qualitatively to identify key points related to force development strategies and lateral asymmetry.

KEYWORDS: swimming, track start, grab start, kinetics, asymmetry.

INTRODUCTION: The grab and the track starts are the two most commonly used starting techniques in competitive swimming. The major difference is how the lower limbs are placed on the block and used to propel the body forward. While the grab start is characterised by a two-legged take-off technique similar to a two-legged jump, the track start simulates the sprint running bunch start which requires an initial rear leg drive, followed by a front leg drive.
While a swimmer may prefer one technique, selection tends to be based on anecdotal beliefs, experience and comfort rather than conclusive scientific evidence. However, studies that have examined biomechanical characteristics of the two starts produced equivocal results (Arellano et al., 2000; Blanksby et al., 2001; Juergens et al., 1999; Miller et al., 2002). Previous investigations of the kinetics of the two starts (Arellano et al., 2000; Juergens et al., 1999; Miller et al., 2002) generally focussed on the total vertical and horizontal impulses, and average vertical and horizontal forces. However, this information provides limited benefits as it is impossible to determine the force development characteristics of the left and right side independently. This is especially a problem for kinetic analyses of the track start, which is asymmetric in nature.
The purpose of this study was to investigate the force profile from the left and right limbs independently during the grab and track start. Information on how the individual limbs are used to generate impulse may provide insights into how swimming starts can be optimised for individual swimmers.

METHODS: Nine male and seven female national and international level swimmers participated in the study. The swimmers were proficient at both starting techniques and were given extra dive start training in the lead-up to the study. They performed 3 trials of grab starts and 3 trials of weight forward track start with the preferred foot in front on a custom-built instrumented starting block, consisting of two force plates mounted side by side. This set-up allowed measurements of ground reaction force from each foot independently. The dimensions of the block were in accordance with regulations set by the world swimming governing body, FINA. Force data were collected at 500Hz and low pass filtered (16 Hz) prior to further analysis.
Temporal and kinetic information, including peak forces (FPEAK), average forces (FAVE) and impulse (I) in the vertical (z) and horizontal (y) directions, reaction time (RT), movement time (MT), block time (BT) and velocity of the centre of gravity at take-off (V), were derived from the force plate data. Time to 6 m (T6m) was used as the criterion measure and synchronised to the kinetic measures via an underwater LED.
Two levels of analysis were conducted to investigate the profiles of the two starting techniques. Firstly, a series of repeated measures Multivariate Analysis of Variance (MANOVA's) were used to examine differences in temporal and kinetic measures between the two starting techniques and to ascertain whether there were any gender effects. Force and impulse variables used in

these analyses were derived from the sum of left and right ground reaction force data.
In addition, force characteristics of the left and right side were examined individually from a qualitative point of view to highlight differences in force development strategies and symmetry between the two sides. It was hypothesised that the grab start would be characterised by symmetrical force profiles in all directions. On the other hand, the front foot of the track start was predicted to generate greater peak force and impulse than the rear foot.

RESULTS AND DISCUSSION: Summary of the net temporal, velocity and kinetic variables are presented in Table 1.

Table 1 Descriptive summary of the temporal, kinetic and velocity variables of the grab and track starts.

	Total (N = 16)		
	Grab	Track	Δ
RT (s)	0.17	0.18	
	(0.03)	(0.03)	
MT (s)	0.78	0.71	*
	(0.04)	(0.06)	
BT (s)	0.94	0.89	*
	(0.04)	(0.07)	
Fy_{PEAK} (N)	925.43	699.22	#*
	(238.28)	(136.10)	
Fz_{PEAK} (N)	1395.86	1365.12	#
	(300.37)	(305.81)	
Fy_{AVE} (N)	397.64	428.68	#*
	(108.90)	(103.23)	
Fz_{AVE} (N)	984.60	919.11	#*
	(176.05)	(194.50)	
Iy (Ns)	308.51	304.51	#
	(84.08)	(75.60)	
Iz (Ns)	765.06	655.15	#*
	(146.06)	(151.94)	
Vy (m/s)	4.23	4.19	#
	(0.51)	(0.37)	
Vz (m/s)	3.04	2.07	#*
	(0.86)	(0.75)	
$V_{Resultant}$ (m/s)	5.27	4.72	#*
	(0.61)	(0.52)	
T_{6m} (s)	2.23	2.24	#
	(0.22)	(0.20)	

Significant gender effects at $p < 0.05$.
*Significant technique differences at $p < 0.05$.

The repeated measure MANOVA and follow up Post hoc analyses revealed significant differences in a number of variables between the grab and track starts. However, only a summary of these results is provided, as this is not the key focus of the paper:

- There were no significant differences in the time to 6m between the two starting techniques.
- MT and BT were significantly shorter for the track start than the grab start but there were no significant differences in RT. No significant gender effects were found.
- In the horizontal direction, greater total FyPEAK was found for the grab start, but the track start generated greater total FyAVE. No significant differences were found in the total Iy, which could be attributed to the shorter MT of the track start.
- In the vertical direction, while no significant differences were found in the total FzPEAK, the grab start displayed greater total FzAVE and total Iz.
- Analysis indicated that greater resultant velocities at take-off were obtained in the grab start. This was predominantly due to greater vertical take-off velocity. It is likely that the longer movement time contributed to this finding.
- Significant differences were also found between males and females in all kinetic variables and velocity variables.
- The results also suggested that FPEAK may not be a good indicator of swimming start performance.

Force Development Characteristics: Figure 2 illustrates the total Fy and Fz for the grab and track starts. Different force characteristics can be observed between the two starts. While the initial movement of swimmers pulling against the starting block with their arms is similar for both grab and track starts, subtle differences can be identified from the force-time curves. In the grab start, this effort is applied mainly in the vertical direction, reflecting the action of pulling the body towards the starting block. This is represented by first elevation of the Fz curves (region 1 on Figure 2a). Conversely, the arm action in the track start appeared to generate impulse in both the horizontal and vertical directions (region 1 on Figure 2b).
In the antero-posterior direction, the grab start was characterised by the gradual development of Fy to reach the peak prior to the swimmer leaving the block. In contrast, the Fy for the track start showed early development and followed by two separate peaks. The first peak corresponded to the push-off from the rear foot and the second peak was generated by the push-off from the front foot (Fig 2).

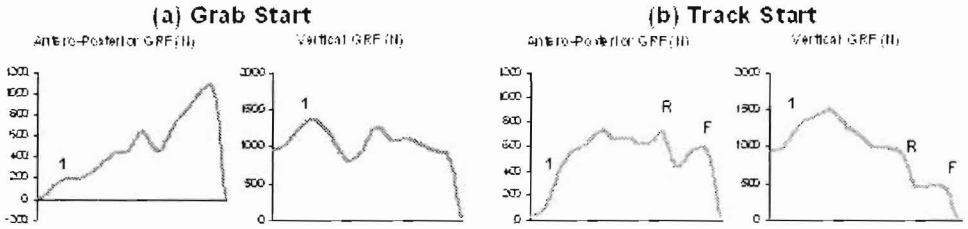

Figure 1: Total Fz and Fy profiles for the grab start (a) and track start (b). For the track start, R marks the first peak corresponding with the rear foot propulsion and F marks the peak corresponding with the front foot propulsion.

Left and Right Comparison for the Grab Start: Currently, it is unclear whether asymmetric force development on the starting block in the grab start has any deleterious effects on starting performance. Possible effects may include unwarranted rotation in the body and displacement in the lateral direction, away from the direct line of projection. As a result, it may be necessary for the swimmers to make some adjustments upon entering the water. Table 2 provides a summary of absolute percentage differences between the left and the right sides in the kinetic variables for the grab start. In the vertical direction, seven of the sixteen participants recorded greater than 10% difference in the FzAVE and nine showed more than 10% difference in Iz.

Table 2 Absolute percentage differences in the kinetic variables for the grab start.

	Fy_{PEAK}	Fz_{PEAK}	Fy_{AVE}	Fz_{AVE}	Iy	Iz
Mean	5.76%	9.62%	7.89%	10.70%	8.09%	10.64%
SD	5.83%	6.86%	3.25%	6.10%	3.23%	6.04%
N over 10%	3	6	4	7	6	9

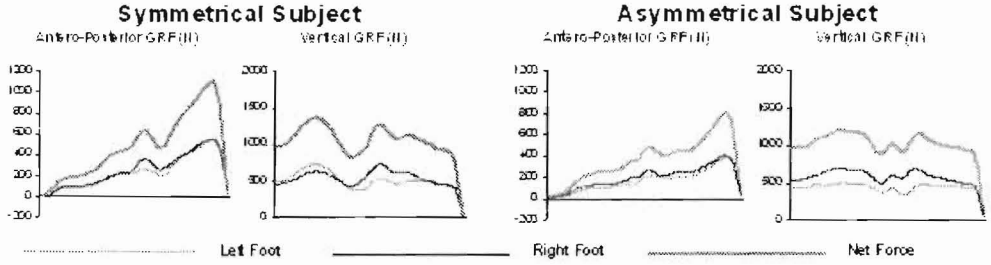

Figure 2: Vertical and horizontal forces for the grab start of a subject with more symmetrical profiles (9% and 4% differences in Iy and Iz) and a subject with asymmetric profiles (10% & 23% differences in Iy and Iz).

Left and Right Comparison for the Track Start: The results from this study showed that MT of the rear foot is approximately 81% of the front foot. With less MT and the centre of mass placed towards the front foot, it was hypothesised that the front foot would generate greater impulse in both y and z direction. However, the results showed a number of subjects with rear foot dominance in both Iy and Iz variables. A cluster analysis with differences in Iy and Iz as determinants was used to classify participants into three groups to reflect their force development strategies (Figure 3).

Group 1 (N = 4) demonstrated rear foot dominant for both Iy and Iz. Groups 2 (N = 6) and 3 (N = 6) showed moderate and large degrees of asymmetry in Iz, respectively. Small differences in Iy were found for groups 2 and 3 but in opposing directions. In terms of performance, the one-way ANOVA with T6m as a dependent variable did not reveal any significant differences between the three groups ($F = 0.42$, $p = 0.67$). However, this result must be taken with caution due to the small sample size. Figure 4 illustrates force profiles from subjects in groups 1 and 3.

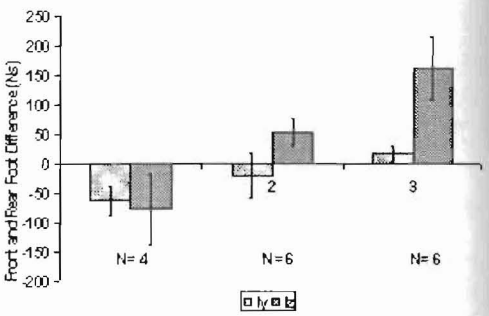

Figure 3: Front and rear foot difference for Iy and Iz in the track start.

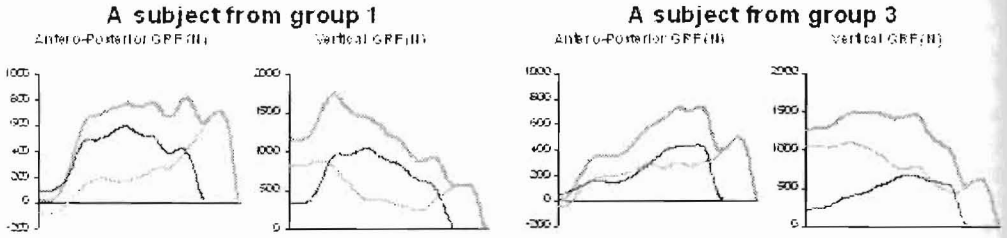

Figure 4: Sample force profile for the track start from group 1 demonstrating greater rear foot impulses, and group 3 demonstrating greater front foot impulses.

CONCLUSION: The ability to measure force profiles of the lower limbs independently can provide useful information regarding force development characteristics of the two swimming starts and increase the scope for further research in optimisation of the starting technique. This is especially so for the track start where the lower limbs are used in a different manner. The current study demonstrated three different front and rear foot interaction patterns in the track start with no significant variations in the performance. Further studies are required to investigate which of these three strategies, if any, might provide the most optimal outcome. In the grab start, the results illustrated varying degrees of asymmetry in a number of participants. While the effects of asymmetric force development on the starting performance are unclear, it warrants further investigation.

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