KINETICS AND KINEMATICS OF THE BLOCK PHASE OF ELITE PARA SWIMMING STARTS

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The present study presents a preliminary overview of dive start performance variables of the block and entry phase of elite para swimmers measured using the Kistler Performance Analysis Swimming System. Insight is given into the variability of these measures. These results can be used as a reference when examining the start phase in training.

KEY WORDS: paralympic, swimming, kinetics.

INTRODUCTION: The introduction of the Kistler Performance Analysis Swimming System (KPASS) to GB's Paralympic (and Olympic) swimmers has made accurate and objective start performance measurements readily available during training. However, in order to interpret and use these data meaningfully, reference values and insight into the variability that can be expected are needed. A set of reference data for able bodied elite swimmers has been published by Mason et al. (2014). However, with the possible exception of intellectually and visually impaired swimmers, these measurements, obtained from an able-bodied population, offer little or no guidance for physically impaired para swimmers across the different classifications (and as such, levels of impairment). Reference data for these populations could also be useful for classification purposes in Para Swimming. This preliminary study aims to construct an overview of reference values of kinematic and kinetic measurements of the block phase of elite para and able-bodied swimming starts. Additionally intra-session variability of these variables will be assessed.

METHODS: This study describes maximal dive start performances of 23 elite swimmers, 15 of whom won medals in the Rio 2016 Paralympic or Olympic Games. The athletes were grouped based upon their official IPC freestyle classification. The nature of the disabilities in these classes (no impairment [AB], intellectual [S14], visual, anthropometrical, neurological or other impairment) was also investigated. The composition of the groups are shown in table 1.

Table 1
Description of athlete group

Group	Class	F	M
ALL ATHLETES		11 F	12 M
NEURO		1 F	2 M
	S7	0	1
	S9	0	1
	S10	1	0
ANTHRO		5 F	1 M
	S5	0	1
	S6	1	0
	S7	1	0
	S8	2	0
	S10	1	0
OTHER		1 F	2 M
	S8	0	1
	S10	1	1
VISUAL		2 F	1 M
	S11	0	0
	S12	1	0
	S13	1	1
S14		1 F	2 M
AB		1 F	4 M

The test session was organized in such a way as to obtain the athlete's maximal start performance. Each swimmer was asked to prepare as for an actual race (race warm-up, wearing race swim suit, …) and then performed between 4 and 6 maximal dive starts to 15 m using their preferred swimming stroke (freestyle, breaststroke or butterfly). Twenty swimmers did a track start, two a single leg start and one a seated start. A full recovery (~ 8 mins) was given between repetitions and no feedback was provided to the athletes.

All starts were performed on the KPASS. This is a commercially available measurement system which combines calibrated sagittal 2D-video (100 Hz, 1 above-water camera positioned orthogonal to the start block and entry phase, 4 below-water cameras from the wall to 18 m down the pool) with force measurements (1000 Hz) recorded separately for the rear foot, front foot and hands. This starting block's dimensions are identical to the official starting blocks used currently in competition (including the adjustable wedge for the back foot).

The performance criterion for a swim start most used by swimming coaches is the time between the start signal and the head touching the 15 m line (15 m – time). These results are reported for each stroke separately as the technical elements during the underwater phase are distinctively different between each of the strokes and, as such, influence the performance criterion to a great extent. The block and flight phase of the start are assumed to be no different between the different strokes. Therefore no further distinction is made when analysing the variables (table 2) associated with these phases. These variables were automatically calculated by the KPASS-software and checked manually for accuracy.

Table 2
Definition of variables.

Variable	Definition
Reaction time (s)	Time from start signal to when the resultant force has increased by 10% bodyweight (BW) compared to the force at the gun.
Block time (s)	Time from start signal to last body part leaving the block.
Max Hor Force (BW)	The peak horizontal resultant force acting on the swimmer. A positive value indicates a forward force.
Max Vert Force (BW)	The peak vertical resultant force acting on the swimmer. A positive value indicates an upward force.
Max Grab Force (BW)	The peak vertical grab force acting upon the swimmer.
Hor Take-Off Velocity (m/s)	The horizontal component of the velocity of the athlete's centre of mass when leaving the block.
Take-Off Angle (°)	The angle between the horizontal and the velocity vector of the athlete's body centre of mass when leaving the block.
Body Lean (°)	The angle between the horizontal and the line connecting the front edge of the block and the centre of the athlete's head at take-off.
Entry Distance (m)	The distance from the wall at which the head enters the water.
Entry diameter (m)	The horizontal distance between the foremost and rearmost points of the body breaking the water at entry.
Entry Velocity (m/s)	The resultant velocity of the athlete's centre of mass when entering the water.
Entry angle (°)	The angle between the horizontal and the velocity vector of the athlete's centre of mass when entering the water.

For all variables the mean, standard-deviation and coefficient of variation were calculated per athlete for the entire session. Intra-class correlation coefficients were above 0.86, indicating that the mean value was representative for the individual. For the variables centred around zero (take-off angle and body lean), the intra-athlete standard-deviation is reported as a measure of intra-athlete variability. For the other variables, the coefficient of variation is given. The means and variations per athlete were used to perform the statistical tests. For the descriptive statistics, the athletes were grouped per freestyle classification and gender. For all athletes in a group (n = number of athletes), the average of their mean session values was calculated (= AVG). Where there was more than one athlete in a group the inter-athlete standard-deviation (= SD) was calculated. The mean and standard-deviation of the intra-athlete coefficient of variation (A CV AVG and A CV SD) was calculated in a similar way. Calculations were performed in Matlab R2015a and Microsoft Excel 2013.

RESULTS: Table 3 shows the time to 15 m for each combination of classification and gender and stroke separately. Table 4 shows the block and entry variables for each classification and gender.

Table 3
Descriptors of 15 m - time sorted according to freestyle classification and gender.

		S5	S6	S7		S8		S9		S10		S12	S13		S14		AB	
		M	F	M	F	M	F	M	F	M	F	F	M	F	M	F	M	F
15m time (s) all strokes	M	9.15	10.91	7.65	9.66	7.84	9.84	7.32	9.11	7.21	8.53	7.86	NaN	9.38	7.65	7.67	6.66	6.38
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.03	NaN	0.09	NaN	NaN	NaN	1.10	NaN	0.56	NaN
	CV	0.8%	0.6%	2.2%	1.6%	0.2%	1.1%	0.7%	1.7%	0.9%	1.1%	1.1%	NaN	1.5%	0.7%	1.3%	1.0%	0.3%
	CV-SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.8%	NaN	0.7%	NaN	NaN	NaN	0.3%	NaN	0.5%	NaN
	(n)	1	1	1	1	1	1	1	2	1	3	1	0	1	2	1	3	1
15m time (s) freestyle	AVG	9.15	10.91	7.65	9.66	7.84	NaN	7.32	8.38	NaN	8.54	7.86	NaN	NaN	6.87	7.67	6.05	6.38
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.12	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	A CV AVG	0.8%	0.6%	2.2%	1.6%	0.2%	NaN	0.7%	2.2%	NaN	1.0%	1.1%	NaN	NaN	0.9%	1.3%	1.1%	0.3%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	(n)	1	1	1	1	1	0	0	1	0	2	1	0	0	1	1	1	1
15m time (s) breaststroke	AVG	NaN	NaN	NaN	NaN	NaN	9.84	NaN	9.98	NaN	NaN	NaN	NaN	9.38	8.42	NaN	6.97	NaN
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.22	NaN
	A CV AVG	NaN	NaN	NaN	NaN	NaN	1.1%	NaN	1.1%	NaN	NaN	NaN	NaN	1.5%	0.5%	NaN	1.0%	NaN
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.8%	NaN
	(n)	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	2	0
15m time (s) butterfly	AVG	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	7.21	8.52	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	A CV AVG	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.9%	1.2%	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
	(n)	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0

Table 4
Descriptors of block and entry variables sorted according to classification and gender.

		S5	S6	S7		S8		S9		S10		S12	S13		S14		AB	
		M	F	M	F	M	F	M	F	M	F	F	M	F	M	F	M	F
reaction time (s)	AVG	0.26	0.16	0.12	0.19	0.21	0.27	0.25	0.25	NaN	0.17	0.20	0.23	0.25	0.23	0.30	0.15	0.15
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.04	NaN	NaN	NaN	0.03	NaN	0.03	NaN
	A CV AVG	18.4%	5.4%	53.8%	10.0%	10.1%	24.3%	6.5%	14.0%	NaN	7.6%	10.2%	46.9%	16.3%	12.3%	16.4%	12.7%	4.7%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.6%	NaN	NaN	NaN	8.2%	NaN	4.4%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
block time (s)	AVG	0.90	0.73	0.91	0.86	0.87	0.77	0.79	0.69	0.65	0.80	0.72	0.72	0.71	0.73	0.85	0.65	0.67
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.08	NaN	NaN	NaN	0.00	NaN	0.03	NaN
	A CV AVG	2.1%	32.1%	5.6%	1.7%	1.8%	5.8%	1.2%	2.2%	0.8%	2.0%	1.4%	2.5%	1.4%	1.9%	2.8%	2.9%	1.3%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.6%	NaN	NaN	NaN	0.2%	NaN	1.4%	NaN
	(n)	1	1	1	1	1	1	1	1	1	3	1	1	1	2	1	4	1
max hor force (BW)	AVG	0.90	1.19	NaN	0.74	0.97	0.93	0.92	1.31	NaN	1.00	1.14	1.18	1.10	1.26	0.93	1.46	1.15
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.16	NaN	NaN	NaN	0.09	NaN	0.21	NaN
	A CV AVG	4.0%	1.6%	NaN	1.9%	2.3%	5.1%	1.3%	2.2%	NaN	2.9%	3.5%	1.3%	3.0%	3.9%	5.4%	1.7%	1.0%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.0%	NaN	NaN	NaN	2.7%	NaN	0.7%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
max vert force (BW)	AVG	1.01	1.38	NaN	1.45	1.23	1.68	1.15	1.39	NaN	1.20	1.16	1.57	1.18	1.48	1.05	1.60	1.34
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.08	NaN	NaN	NaN	0.03	NaN	0.07	NaN
	A CV AVG	1.3%	4.2%	NaN	1.5%	2.2%	3.8%	3.1%	5.0%	NaN	3.6%	5.8%	5.0%	4.1%	2.5%	1.9%	4.7%	8.1%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.8%	NaN	NaN	NaN	1.2%	NaN	2.4%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
max grab force (BW)	AVG	NaN	0.52	NaN	0.06	0.72	1.05	0.96	0.21	NaN	0.61	0.97	0.10	0.75	0.91	0.77	1.00	1.09
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.40	NaN	NaN	NaN	0.18	NaN	0.12	NaN
	A CV AVG	NaN	3.9%	NaN	34.7%	10.5%	2.8%	3.3%	9.2%	NaN	22.0%	3.6%	37.7%	10.0%	6.8%	3.3%	3.2%	0.8%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	27.5%	NaN	NaN	NaN	6.1%	NaN	1.3%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
hor take-off velocity (m/s)	AVG	4.05	3.17	NaN	3.14	4.14	2.60	4.13	4.13	NaN	3.70	4.24	4.05	3.97	4.24	4.05	4.50	4.30
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.10	NaN	NaN	NaN	0.03	NaN	0.28	NaN
	A CV AVG	0.8%	0.8%	NaN	2.0%	1.1%	2.2%	1.8%	1.3%	NaN	0.9%	2.2%	1.0%	1.6%	2.4%	1.7%	1.6%	0.5%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.4%	NaN	NaN	NaN	0.9%	NaN	0.8%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
take-off angle (°)	AVG	-23.00	-19.33	NaN	-6.67	-27.00	-16.67	-16.50	-7.00	NaN	-15.21	-14.00	-3.25	-15.25	-0.40	-19.83	-3.67	-3.80
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	7.13	NaN	NaN	NaN	0.85	NaN	3.50	NaN
	A SD (AVG)	1.58	1.21	NaN	0.52	1.41	1.21	0.58	1.87	NaN	1.53	1.26	2.22	1.50	1.08	1.83	1.74	0.84
	A SD (SD)	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.40	NaN	NaN	NaN	1.53	NaN	0.23	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
body lean (°)	AVG	-10.60	2.88	10.25	17.00	-0.60	-1.50	11.00	15.90	16.33	9.28	10.25	22.00	8.75	21.00	3.17	19.60	23.60
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.84	NaN	14.11	NaN	NaN	NaN	2.83	NaN	2.98	NaN
	A SD (AVG)	1.9%	23.5%	5.1%	1.5%	1.6%	4.5%	1.0%	1.5%	0.5%	1.6%	1.0%	1.8%	1.0%	1.4%	2.3%	1.9%	0.9%
	A SD (SD)	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.1%	NaN	0.4%	NaN	NaN	NaN	0.1%	NaN	1.0%	NaN
	(n)	1	1	1	1	1	1	1	2	1	3	1	1	1	2	1	4	1
entry distance (m)	AVG	2.07	1.84	3.06	2.21	2.30	1.28	2.83	2.80	2.69	2.59	2.63	3.01	2.36	3.12	2.42	3.12	2.95
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.21	NaN	NaN	NaN	0.22	NaN	0.15	NaN
	A CV AVG	0.9%	1.5%	3.2%	1.0%	2.4%	2.4%	0.8%	0.6%	1.3%	1.3%	1.3%	1.3%	0.6%	1.0%	2.1%	1.3%	0.6%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.5%	NaN	NaN	NaN	0.1%	NaN	0.3%	NaN
	(n)	1	1	1	1	1	1	1	1	1	3	1	1	1	2	1	4	1
entry diameter (m)	AVG	0.55	0.74	1.10	0.44	1.19	0.53	1.11	0.63	0.56	1.02	0.74	0.44	0.63	0.87	0.50	0.76	0.64
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.05	NaN	NaN	NaN	0.15	NaN	0.17	NaN
	A CV AVG	3.8%	3.1%	10.2%	19.5%	3.5%	14.7%	5.8%	8.9%	10.7%	5.1%	13.6%	8.6%	17.5%	6.0%	9.8%	9.5%	9.7%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	2.3%	NaN	NaN	NaN	4.1%	NaN	1.9%	NaN
	(n)	1	1	1	1	1	1	1	1	1	3	1	1	1	2	1	4	1
entry velocity (m/s)	AVG	6.06	5.68	6.40	6.01	6.35	4.82	6.28	6.12	NaN	6.16	6.28	6.47	6.00	6.54	6.50	6.66	6.53
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.25	NaN	NaN	NaN	0.11	NaN	0.10	NaN
	A CV AVG	0.6%	0.6%	3.4%	1.2%	0.8%	0.6%	0.6%	0.8%	NaN	0.9%	1.0%	0.8%	0.8%	1.3%	0.9%	0.8%	0.6%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.6%	NaN	NaN	NaN	0.0%	NaN	0.2%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1
entry angle (°)	AVG	48.20	55.33	51.00	58.33	49.40	57.83	49.75	47.60	NaN	52.87	47.83	51.25	49.25	50.33	51.33	47.87	49.00
	SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	1.86	NaN	NaN	NaN	0.11	NaN	2.27	NaN
	A CV AVG	0.9%	0.9%	3.6%	1.4%	1.1%	1.3%	1.0%	1.2%	NaN	0.4%	2.4%	1.0%	1.9%	1.5%	1.6%	1.6%	0.0%
	A CV SD	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.6%	NaN	NaN	NaN	0.6%	NaN	0.7%	NaN
	(n)	1	1	1	1	1	1	1	1	0	3	1	1	1	2	1	3	1

DISCUSSION: These preliminary data give insight into how the variables constituting start performance vary across gender and classifications. A qualitative observation shows that in general and as to be expected, there is a better start performance as the classification number increases (i.e. level of swimming-specific impairment decreases).

Although all athletes were asked to do a maximal dive start for each trial, the results show variability in the outcome variable. It seems that some athletes (both para and AB) are able to replicate maximal performance with minimal variability, whereas others cannot do this. For now statistical power is too limited to distinguish the effect of the nature of the disability or classification on variability of movement execution. As the dataset grows, this could be one of the areas for future research.

The average coefficient of variation for time to 15 m was 1.1 % for all athletes participating in the study. Three athletes achieved a coefficient of variation lower than 0.3 % in their time to 15 m, the difference between their fastest and slowest trial varying by only 0.03 to 0.06 seconds. These athletes were an able-bodied athlete, an athlete with an anthropometrical impairment and an athlete with muscular dystrophy. The two most variable athletes in their time to 15 m showed a coefficient of variation greater than 2%, with a 0.36 to 0.43 s difference between their fastest and slowest times. These athletes both had a neurological impairment. Do athletes that are very consistent in the outcome measurement also exhibit less variability in the technical execution of the block and entry phase? The two least variable swimmers (both para) in terms of outcome measure (15 m – time) are situated halfway through the participant group when ranking swimmers from least to most variable on each of the measurements. This could be an indication of the swimmers being able to use compensational mechanisms. The third most consistent swimmer (AB) was for all measurements among the most consistent athletes. It must be acknowledged that the underwater phase of the start is not included in these data and that this phase influences 15m-time to a great extent (Burkett et al., 2010).

CONCLUSION: The present data offer insight into performance and variability during the above-water phase for elite para swimmers' dive starts. They can be used as a reference when doing technical work on the start phase. Certain para-athletes are able to deliver a performance with the same consistency as the least variable AB-athlete in the study. Nevertheless, the para athletes' variability in the actual execution of the movements is higher, pointing at their ability to exploit compensational mechanisms to deliver a stable performance. The athletes with the greatest difficulty to deliver a consistent performance seem to be the ones that suffer from neurological impairments. Further research on a larger sample size is needed to investigate these findings in more detail.

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