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KINEMATIC CHARACTERISTICS OF THE LONG JUMP APPROACH RUN IN PARALYMPIC-LEVEL MALE LIMB-DEFICIENTS

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ABSTRACT

The purpose of this study was to define the variables typifying the long jump approach run phase in paralympic-level male amputees. The sample comprised of the eleven (4 transtibial, 5 transfemoral and 2 single below-the-knee amputees). The parameters analysed were: official distance, toe-to-board distance, effective distance, stride contact time, stride flight time, total stride time, stride length, stride frequency, stride velocity, horizontal velocity, vertical velocity, resultant velocity, height of body center of mass, take-off stride angle, relative differences in stride length and relative differences in stride frequency. The findings of the study revealed that 77.8% of the para-athletes perform the take-off with the leg supported by the prosthesis. Horizontal velocity during the last three strides before take-off has been shown to have a high correlation with the official jump distance: 3rd last ($r=0.65$, $p<0.05$), 2nd last ($r=0.69$, $p<0.05$) and last ($r=0.67$, $p<0.05$) strides. Stride length and stride frequency patterns for the 3rd, 2nd and last strides were as follows: medium-long-short and high-low-high. Horizontal velocity at the last stride is higher compared to the preceding two. The findings of the study support the notion that a wide range of similarities exist in the running patterns and factors correlating with jumping distance between Paralympic amputee athletes and able-bodied high-level athletes.

Keywords: biomechacnics, atheltics, transtibial, transfemoral, prosthesis

CARACTERÍSTICAS CINEMÁTICAS DE LA CARRERA DE APROXIMACIÓN DEL SALTO DE LONGITUD, EN ATLETAS PARALÍMPICOS

RESUMEN

El objetivo del estudio fue definir las variables de la carrera de longitud, en su fase última, de atletas con amputación. La muestra comprendía 11 atletas paralímpicos. Se analizó: distancia oficial, distancia entre el pie y la tabla, distancia efectiva, tiempo de contacto del paso, del vuelo y tiempo total, longitud, frecuencia y velocidad del paso, velocidad horizontal, vertical y resultante, altura del centro de masa corporal del paso, ángulo de despegue, diferencias relativas en la longitud del paso y en la frecuencia. Se encontró que el 77.8% de atletas realizaron la batida con la pierna apoyada por la prótesis. Se ha demostrado que la velocidad horizontal durante los últimos tres pasos tiene una alta correlación con la distancia oficial de salto: 3º último ($r=0,65$, $p<0,05$), 2º último ($r=0,69$, $p<0,05$) y último ($r=0,67$, $p<0,05$). Los patrones de los tres últimos pasos fueron medio-largo-corto y de frecuencia alto-bajo-alto. La velocidad horizontal en el último paso es más alta en comparación con las dos anteriores. Este estudio apoya la noción de que existe una similitud en los patrones de carrera y la correlación con la distancia de salto, similar a los atletas sin discapacidad.

Palabras clave: biomecánica, atletismo, amputado tibial, amputado femoral, prótesis

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INTRODUCTION

The approach run and take-off phase are key components of success in the long jump event. Numerous biomechanical studies have been conducted in long jump able-bodied athletes in order to determine which is the optimal technique for maximal performance (Hartmann, 1987; Schiffer, 2011). However, we've found little research about optimal long jump performance techniques and the underlying biomechanics for disabled athletes, specifically those with lower extremity amputations (Rice et al., 2011; Simpson, Williams, Hsiu-Ling, Nance, & Valleala, 1998; Beckman, Connick,McNamee, Parnell & Tweedy, .,2017). The different techniques obtained from the existing studies have been incorporated into training and coaching in order to improve the results in this event (Bridgett & Linthorne, 2006; Hay, 1993). The only research we have found comparing non disabled high-level athletes and paralympic-level athletes (Willwacher, Funken, Heinrich, Müller, Hobara, Grabowski, Brüggemann & Potthast, 2017) the former F42-F44, currently T63, T64 and T44 (International Paralympic Committee, 2019), long jump amputee athletes in elite level competitions.

Performance techniques for able-bodied athletes and lower extremity amputees differ in regards to loss of musculoskeletal tissue and the use of a prosthetic component (Ciapponi, 2000). Performances achieved by para-athletes with limb-deficiency are limited by their asymmetrical gait, something that may have a negative impact on their achieved run-up velocity. A different technique is necessary when velocity varies (Bridgett & Linthorne, 2006). The long jump event consists of five phases: approach run, take-off preparation, take-off, flight and landing. The key factor in the take-off preparation is maintaining as much of the horizontal velocity obtained in the approach phase with minimal loss (Isakov, Burger, Krajnik, Gregoric, & Marincek, 1996). There is a major correlation between the horizontal velocity of the body centre of mass (BCM) during the approach run, the take-off phases and the jumping distance (Shimizu, Ae, & Koyama, 2011).

The purpose of this study was to define the variables typifying the long jump approach run phase in class F42-F44 high-level level male amputees and compare them with those obtained from high-level non-amputee long jumpers. It was hypothesized that the long jump finalists at the 2012 London Paralympic Games would exhibit similar technical and biomechanical abilities during the run-up, compared to peers without disabilities. This knowledge would be useful for coaches seeking methods to improve training and overall performance of amputee athletes.

METHOD

Participants

The classification of the athletes used in this article is the classification used in the Paralympic Games London 2012. Currently the International Paralympic Comitee is using a new classification (International Paralympic Committee, 2019).

The F42-44 male long jump finalists at London 2012 Paralympic Games (11 athletes aged 28.7±6.59) were recorded during the finals of the event. Approval for the investigation was obtained from the university's ethics committee and the International Paralympic Committee. These athletes belong to this amputee class because they suffer a single below-the-knee amputee, a single above-the-knee amputee or an impairment equivalent to single below–the-knee amputees. In compliance with the Data Protection Act, athletes have been assigned a number for identification purposes.

The codification of the athletes were made using the order in the first round.

Participants of class F44 (currently T64): 4 single below-the-knee amputees, transtibial amputees (athletes' number 1, 2, 6 and 8).

Participants of class F44 (currently T44): 2 athletes without prosthesis affected by limb deficiency, leg length difference, impaired muscle power or impaired passive range of movement (athletes' number 5 and 10).

Participants of class F42 (currently T63): 5 single above-the-knee amputees, transfemoral amputees (athletes' number 3, 4, 7, 9 and 11).

Additionally, the biomechanical analysis of the performances of 8 high-level male long jumpers participating at the IAAF Athletics World Championship held in Berlin on 2009 were also used (Mendoza & Nixdorf, 2011).

Data collection

Four Exilim-F1 cameras (Casio computer, Co. Ltd., Japan) were arranged in the following fashion: two cameras recording at high speed (640x480 pixels at 300 fps) from the beginning of the approach run up to the pit, in order to obtain temporal data (panning cameras). Two cameras recording in high definition (1280x720 pixels at 30 fps) were placed at the spectators' area (20m horizontal distance from the run-way and 5m elevated to the vertical) with their optical axis perpendicular to the same area. One was placed 10m prior to take-off board and the other perpendicular to the take-off board (fixed cameras). The speed was measured with a Stalker ATS 5.02 radar (Applied Concepts Inc., USA) at a frequency of 48Hz. The radar was positioned 10m in front of the end of the long jump pit. The calibration of the approach run was done using black markers (5x5cm) placed at one-meter intervals on the external side of the run-up track. The validity of the procedure was assessed by recording running shoes placed at known distances along the runway (Theodorou & Skordilis, 2012; Theodorou, Skordilis, Plainis, Panoutsakopoulos, & Panteli, 2013).

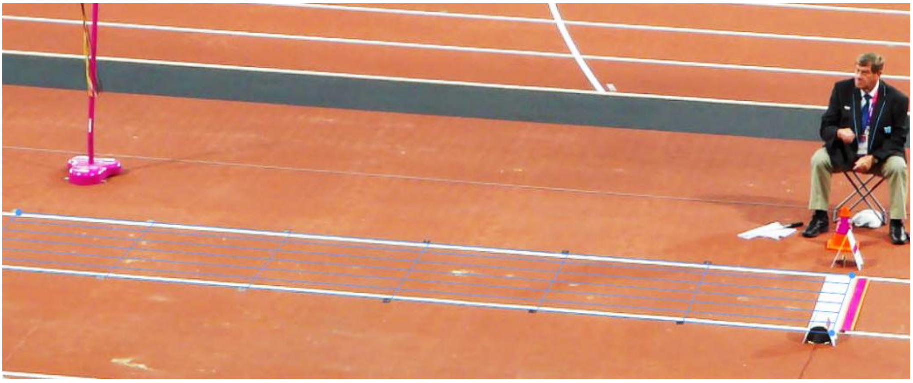

FIGURE 1: The calibration of the approach run was with white markers (5x5cm) in the Olympic Stadium (London 2012).

Data reduction

All the attempts of the men's F42-F44 final were recorded. The best valid jump of each participating athlete in the final was selected for further analysis and processed with Dartfish Pro-Suite 2010 software (Dartfish, Switzerland).

The variables analysed in the last three strides of the approach run refer to space, time, speed and angle.

These variables are shown in the table below.

TABLE 1
Biomechanical parameters, abbreviations used and the definitions and methods used for determining the parameters.

Variable	**Abbr**	**Unit**	**Definition and method**
Official distance	D_{OFF}	m	Distance at X-axis from the take-off line to the nearest break in the landing area made by any part of the body.
Toe-to-board distance	D_{TTB}	m	Distance at X-axis from the toe of the take-off foot to the take-off line.
Effective distance	D_{EFF}	m	The horizontal distance the athlete has to jump, measured from the toe of the take-off foot at the time of take-off to the nearest mark made by the athlete in the sand: DOFF + DTTB.
Contact time	TC_3, TC_2, TC_1	s	Time of foot contact on the floor for the antepenultimate, penultimate and last strides respectively
Flight time	TF_3, TF_2, TF_1	s	Time that the athlete is in the air for the antepenultimate, penultimate and last strides respectively
Stride time	TS_3, TS_2, TS_1		Sum of $Tc_3 + TF_3$; $TC_2 + TF_2$; $TC_1 + TF_1$ respectively.
Stride length	LS_3, LS_2, LS_1	m	Distance at X-axis between toe-off point to the next toe-off point of the last 3 approach strides.
Stride frequency	FS_3, FS_2, FS_1	Hz	Number of strides that the athlete takes over per second for the antepenultimate, penultimate and last strides respectively.
Stride velocity	VS_3, VS_2, VS_1	m/s	Stride velocity during the last 3 approach strides calculated as average stride velocity from the first ground contact of one stride to the first ground contact of the next stride: LS/TS
Horizontal velocity during the last 3 strides	Vx_3, Vx_2, Vx_1	m/s	BCM velocity at X-axis at the time of take-off for the antepenultimate, penultimate and last strides measured by radar.
Vertical velocity during the last 3 strides	Vy_3, Vy_2, Vy_1	m/s	BCM velocity at Y-axis at the time of take-off for the antepenultimate, penultimate and last strides: 9,8*TF/2
Resultant velocity	Vr_3, Vr_2, Vr_1	m/s	Resultant velocity for the antepenultimate, penultimate and last strides: $(Vx^2+Vy^2)^{-2}$
BCM height	h_3, h_2, h_1	m	BCM height at Y-axis at the flight phase for the antepenultimate, penultimate and last strides: $1{,}225*TF^2$
Take-off stride angle	a_3, a_2, a_1	º	Velocity angle at the take-off during the run-up for the antepenultimate, penultimate and last strides: $\tan^{-1}(Vy/Vx)$.
Relative difference stride length	$RdL_{2/3}$	%	The percentage length difference between on-approach stride and the previous one, for the penultimate and the antepenultimate strides: LS_2/LS_3*100
Relative difference stride length	$RdL_{1/2}$	%	The percentage length difference between on-approach stride and the previous one, for the last and penultimate strides: LS_1/LS_2*100
Relative difference stride frequency	$RdF_{2/3}$	%	The percentage frequency difference between on-approach stride and the previous one, for the penultimate and the antepenultimate strides: 2FS/3FS*100
Relative difference stride frequency	$RdF_{1/2}$	%	The percentage frequency difference between on-approach stride and the previous one, for the last and penultimate strides: 1FS/2FS*100

Data analysis

In order to analyse the data, descriptive statistics were used (mean, standard deviation, median, minimum and maximum values). Due to the fact that the study group was relatively small, a non-parametric Mann-Whitney U test was used, in order to compare two groups . The relationship between the result dependent variables (D_{OFF} and D_{EFF}) was analysed using the coefficient correlation of Spearman. A value of $p<0.05$ was considered statistically relevant. The statistical analysis of the data was performed using PASW V.18.0.0 software (SPSS, Chicago, Illinois, USA). The effect size was calculated using Cohen's δ as a measure of means differences unrelated to group sizes (Cohen, J., 1988).

RESULTS

Detailed data are presented in tables 1, 2, and 3. Despite the fact that the F42 and F44 athletes compete in the same classification, the results obtained both in D_{OFF} and D_{EFF} differ considerably, as the F44 group clearly achieved better results. The average D_{OFF} for class F42 athletes was 5.28±1.03m, whereas for class F44 athletes 6.30±0.58m.

When comparing the London group and the Berlin group there were significant differences ($p<0.001$) in most of the analysed variables: D_{OFF}, D_{EFF}, LS_3 and LS_1, Vx_3, Vx_2 and Vx_1,resulting in better parameter in Berlin group than London.

TABLE 2
Event scorecards: athlete number, class, take-off leg, official distance, effective distance, toe-to-board distance, and wind. Long jump class F42-44 2012 at London Paralympic Games.

ATHLETE NUMBER	**Class**	**T_O leg**	**D_{OFF} (m)**	**D_{EFF} (m)**	**D_{TTB} (m)**	**Wind (m/s)**
1	44	1	6.19	6.22	0.03	0.9
2	44	1	6.33	6.40	0.07	0.8
3	42	0	4.06	4.24	0.18	0.4
4	42	1	6.11	6.23	0.12	0.8
5	44	0	6.12	6.16	0.04	0.3
6	44	0	5.56	5.59	0.03	1.0
7	42	1	6.07	6.15	0.08	1.0
8	44	1	7.35	7.48	0.13	1.2
9	42	1	4.25	5.01	0.76	-1.6
10	44	0	6.27	6.32	0.05	1.1
11	42	1	5.95	5.99	0.04	1.2
Mean			5.84	5.98	0.14	0.65
SD			0.93	0.82	0.03	0.8

Note: TO leg: 1-Prosthesic; 0- Non prosthetic

TABLE 3
Parameters related to the last three strides before take-off. Long jump class F42-44 at 2012 London Paralympic Games.

ATHLETE NUMBER	TC_3 (s)	TF_3 (s)	TS_3 (s)	FS_3 (Hz)	LS_3 (m)	VS_3 (m/s)	Vx_3 (m/s)	h_3 (cm)	Vy_3 (m/s)	Vr_3 (m/s)	a_3 (º)
STRIDE 3											
1	0.107	0.143	0.25	4.00	2.07	8.28	8.48	2.51	0.70	8.51	4.72
2	0.110	0.126	0.236	4.24	1.88	7.97	7.97	1.94	0.62	7.99	4.43
3	0.157	0.143	0.300	3.33	1.88	6.27	6.28	2.51	0.7	6.32	6.37
4	0.103	0.117	0.22	4.55	1.78	8.09	8.12	1.68	0.57	8.14	4.04
5	0.110	0.113	0.223	4.48	1.92	8.61	8.76	1.56	0.55	8.78	3.62
6	0.117	0.120	0.237	4.22	1.83	7.72	7.99	1.76	0.69	8.01	4.21
7	0.100	0.067	0.167	5.99	1.47	8.8	8.02	0.55	0.33	8.03	2.34
8	0.100	0.107	0.207	4.83	1.77	8.55	8.58	1.40	0.52	8.6	3.50
9	0.110	0.130	0.24	4.17	1.82	7.58	7.42	2.07	0.64	7.45	4.91
10	0.093	0.091	0.183	5.46	1.68	9.18	8.50	1.01	0.45	8.51	3.00
11	0.097	0.123	0.220	4.55	1.79	8.14	8.22	1.85	0.6	8.24	4.19
Mean	0.109	0.116	0.226	4.53	1.81	8.11	8.03	1.71	0.57	8.05	4.12
SD	0.017	0.022	0.035	0.720	0.150	0.77	0.69	0.58	0.11	0.68	1.06
STRIDE 2											
1	0.124	0.156	0.280	3.57	2.30	8.50	8.38	2.98	0.76	8.41	5.21
2	0.107	0.153	0.260	3.85	2.02	7.77	7.77	2.87	0.75	7.81	5.51
3	0.13	0.177	0.307	3.26	1.96	6.38	6.32	3.84	0.87	6.38	7.81
4	0.113	0.177	0.290	3.45	2.38	8.21	8.23	3.84	0.87	8.28	6.02
5	0.100	0.130	0.230	4.35	2.16	9.39	9.01	2.07	0.64	9.03	4.04
6	0.110	0.137	0.247	4.05	2.03	8.22	8.34	2.30	0.67	8.37	4.60
7	0.110	0.137	0.247	4.05	1.81	7.33	7.40	2.30	0.67	7.43	5.18
8	0.090	0.117	0.207	4.83	1.96	9.47	9.49	1.68	0.57	9.51	3.46
9	0.147	0.210	0.357	2.80	2.51	7.03	7.03	5.40	1.03	7.10	8.33
10	0.113	0.150	0.263	3.80	2.11	8.02	8.42	2.76	0.74	8.45	4.99
11	0.097	0.106	0.203	4.93	1.68	8.28	8.36	1.38	0.52	8.38	3.56
Mean	0.113	0.150	0.263	3.90	2.08	8.05	8.07	2.85	0.74	8.10	5.34
SD	0.016	0.030	0.045	0.64	0.24	0.92	0.89	1.15	0.15	0.88	1.57
LAST STRIDE											
1	0.110	0.074	0.184	5.43	1.89	10.27	8.64	0.67	0.36	8.65	2.4
2	0.104	0.093	0.197	5.08	1.92	9.75	8.22	1.06	0.46	8.23	3.17
3	0.130	0.063	0.190	5.26	1.42	7.47	6.65	0.49	0.31	6.66	2.66
4	0.113	0.084	0.197	5.08	1.91	9.70	8.27	0.86	0.41	8.28	2.85
5	0.103	0.077	0.18	5.56	1.87	10.39	9.06	0.73	0.38	9.07	2.38
6	0.113	0.063	0.176	5.68	1.81	10.28	8.35	0.49	0.31	8.36	2.12
7	0.100	0.063	0.163	6.13	1.59	9.75	8.36	0.49	0.31	8.37	2.11
8	0.103	0.090	0.193	5.18	1.92	9.95	9.63	0.99	0.44	9.64	2.62
9	0.127	0.119	0.246	4.07	2.06	8.37	7.27	1.73	0.58	7.29	4.59
10	0.093	0.090	0.183	5.46	1.85	10.11	9.10	0.99	0.44	9.11	2.77
11	0.107	0.107	0.214	4.67	1.95	9.11	8.51	1.40	0.52	8.53	3.53
Mean	0.109	0.084	0.193	5.24	1.84	9.56	8.37	0.90	0.41	8.38	2.84
SD	0.011	0.018	0.022	0.54	0.18	0.91	0.83	0.40	0.09	0.83	0.72

TABLE 4
Relative differences in stride length and stride frequency of the three last strides. Long jump class F42-44 2012 at London Paralympic Games.

ATHLETE NUMBER	$RdL_{2/3}$ (%)	$RdL_{1/2}$ (%)	$RdF_{2/3}$ (%)	$RdF_{1/2}$ (%)
1	11.1	-17.8	-10.7	52.2
2	7.4	-5.0	-9.2	32.0
3	4.3	-27.6	-2.3	61.6
4	33.7	-19.7	-24.1	47.2
5	12.5	-13.4	-3.0	27.8
6	10.9	-10.8	-4.0	40.3
7	23.1	-12.2	-32.4	51.5
8	10.7	-2.0	0.0	7.3
9	37.9	-17.9	-32.8	45.1
10	25.6	-12.3	-30.4	43.7
11	-6.1	16.1	8.4	-5.1
Mean	15.6	-11.2	-12.8	36.7
SD	13.1	11.4	14.6	20.1

DISCUSSION

The take-off preparation phase has been studied separately within the approach run (Bae, 2011; Mendoza & Nixdorf, 2011). The analysis of the last three strides has been shown to have a correlation with the take-off and D_{OFF} and D_{EFF}.

Velocity and time

The most important factor in the take-off preparation for the long jump is to maintain as much of the horizontal velocity obtained in the approach as possible and transform it into great vertical velocity, with minimum loss at the take-off stage (Isakov et al., 1996). Some researchers have reported a correlation between the value of the speed of approach and both D_{OFF} and D_{EFF} of the jump (Nixdorf & Brüggemann, 1990). The variables for Vx have been shown to have a greater correlation with both D_{OFF} and D_{EFF}. The results for the D_{OFF} are: LS_3 ($r=0.65$, $p<0.05$), LS_2 ($r=0.69$, $p<0.05$) and LS_1 ($r=0.67$, $p<0.05$), whereas for D_{EFF}, the greater correlation was found in the Vx at the LS_2 stride ($r=0.61$, $p<0.05$). For the Berlin group, the correlation coefficient between approach velocity and D_{EFF} is quite similar ($r=0.69$) (Mendoza & Nixdorf, 2011). In previous studies for different competitions, the highest correlation between approach velocity and D_{EFF} was found in the last stride (Nixdorf & Brüggemann, 1990). Overall, there was a relatively high correlation between the approach velocity and D_{EFF} achieved, although the correlation coefficient is not as high as in other studies (Hay, 1986; Lees, Fowler, & Derby, 1993; Nixdorf & Brüggemann, 1990). When individually analyzed, the winners of both competitions achieved the highest velocity at the last stride, which shows the importance of the highest velocity being in the last stride.

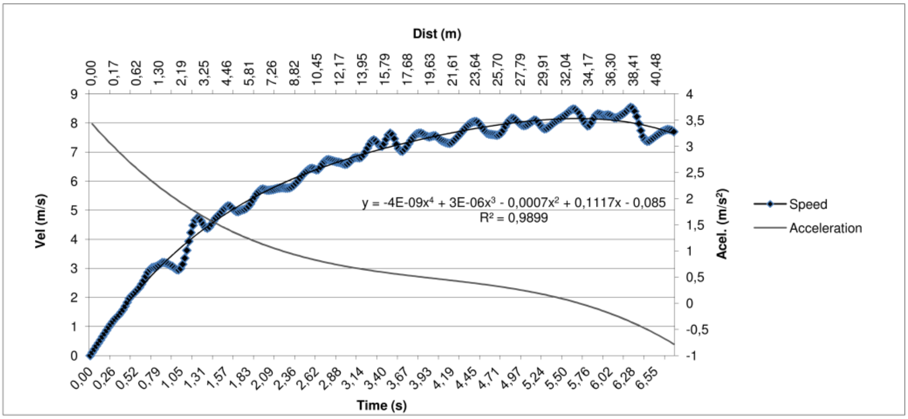

FIGURE 2: Instantaneous velocity and acceleration as a function of distance and time (London 2012).

The causes for the observed variations in the Vx velocity during the last three strides are found in the support phases of these strides, which are determined by the stride length, the position of the body segments at touchdown and take-off, and the movements of the take-off leg and the lead leg (Nixdorf & Brüggemann, 1990). There is hardly any bibliography on studies measuring contact time (TC) and flight time (TF) in the last strides during the approach run in the long jump. Data for these time scores in the Berlin group was never published. However, for the London group, since the recordings were done at 300fps, we consider that this speed is high enough for experts to obtain valid results. For comparative purposes, the results for the men's final at Seoul 1988 (Nixdorf & Brüggemann, 1990) were used.

When analysing the TC in each one of the last three strides in the London group, the following average values can be observed: 0.109±0.017s (LS_3), 0.112±0.016s (LS_2), 0.109±0.011s (LS_1). We can see that the values for each one of the three contact times are stable; there are no major differences between them. This data was compared with the data published at Seoul 1988: 0.088±0.005s (LS_3), 0.080±0.009s (LS_2), 0.103±0.008s (LS_1). The effect sizes measure with Coen's δ are 1.67, 2.46 and 0.62 respectively. TC for able-bodied athletes is obviously lower because their velocity is higher. TC, TF and LS have a direct impact on the change of BCM velocity in the last strides. From the above comparison, it is noted that the athletes competing at Seoul 1988 lengthen TC in the LS_1, whereas the London group shorten it slightly. The average time value of the 11 TC made with the prosthesis is slightly lower (0.109s) compared to the 11 TC using their foot (0.110s), although the differences are minor. Athlete number 8, who is the fastest athlete and also the one who jumps the furthest, has the lowest contact times (0.097±0.009s), which is comparable to the Paraolympic athletes at Seoul 1988. We can thus conclude that lower contact times achieve higher approach velocity, which is decisive in the distance of the jump. No significant differences were found between TC with prosthesis.

Several researchers found a significant correlation between the approach speed and the length of the jump (Nixdorf & Brüggemann, 1990). The following regression equation (($D = 0.021v^2+0.725v-1,65$ were: D=effective distance of the jump (m); v=approach speed (m/s)) has been reported by Tiupa, Aleshinsky, Primakov, and Pereverzev (1982). An increase in run-up speed of 0.1m/s was followed by a corresponding increase in distance of the jump of 0.12m (Karas, Susanka, Otahal, & Moravkova, 1983). In the present study, when comparing London and Berlin groups, we could observe that an increase of 0.1m/s in BCM velocity at X-axis at the time of take-off for the last strides help increase D_{OFF} by 0.11m. For the London group, the average Vx was 8.03m/s, 8.07m/s and 8.37m/s, respectively. This means that the last stride is the fastest, which differs from results obtained in previous research with high-level able-bodied athletes, where there is a loss of velocity in the last stride. Vx for the 8 finalists in Berlin (10.46m/s, 10.52m/s and 10.40m/s, respectively) indicates that the loss in Vx occurs during the support phase of the last stride. In able-bodied long jumpers, the approach velocity slightly increased in the LS_2 and then decreased in the LS_1 for almost all the athletes. This fact is related to the LS design (Mendoza & Nixdorf, 2011), which means when the length of the last stride decreases, so does the velocity. For the London group, despite the fact that the length of the last stride decreased, the velocity increased, thus creating a major difference between both groups. All finalists in the London group increased their velocity in the last stride. That was produced by the severe increase in step frequency, from 3.90±0.64 Hz to 5.24±0.54 Hz.

Stride length

A parameter that significantly affects velocity and thus long jump performance is the stride length. Athletes tend to use a medium-long-short stride pattern, which means that they shorten the length of the last step after a longer stride (Nigg, 1974; Nixdorf & Brüggemann, 1990). It has been suggested that the tendency of variations in stride length must be considered in conjunction with the path of the BCM and the forward or backward orientation of the body during the last strides when the athlete prepares for the take-off. The stride pattern of the last three strides used by the athletes in the London group is clearly medium-long-short, with average values of 1.81±0.15m, 2.08±0.24m and 1.84±0.18m, following the pattern of high-level able-bodied athletes. When comparing the data with the Berlin group, the results were very similar pattern 2.28±0.09m, 2.46±0.14m and 2.21±0.14m. When comparing both finals, only one athlete in each competition lengthens the last stride. The effect sizes measure with Coen's δ are 3,80, 1,93 and 2,29 respectively.

In the London group, the LS_2 stride was larger by an average of 0.27m (15.6%) in comparison with the LS_3. The large dispersion within this movement pattern is notable. When comparing the data with the Berlin group, the percentage of the extension in the LS_2 to the LS_3 stride is smaller (6%). Athletes lengthening this stride must then shorten the last stride in order to get to the take-off. The relation between the LS_2 and the LS_1 stride shows that athletes tend to shorten their step an average of 0.24m (11.2%). Athletes in the Berlin group also shorten it an average of 0.24m (9%). There are major differences amongst the athletes of the London group, although it should be noted that, among the athletes that lengthen the stride length and those who shorten the length of their last stride by a greater percentage are also the ones that lengthen the penultimate stride by a smaller percentage. There is not a significant correlation between the length of the last three strides and D_{OFF} and D_{EFF} in the London and Berlin groups. This could be due to fact that the analysed sample is too small, but when joining the athletes from both groups (n=19), we find that there is a significant correlation with the D_{OFF} and D_{EFF} distances in LS_3 ($r=0.71$ and $r=0.70$, $p<0.05$), LS_2 ($r=0.56$, $p<0.05$) and LS_1 ($r=0.75$, $p<0.001$), respectively.

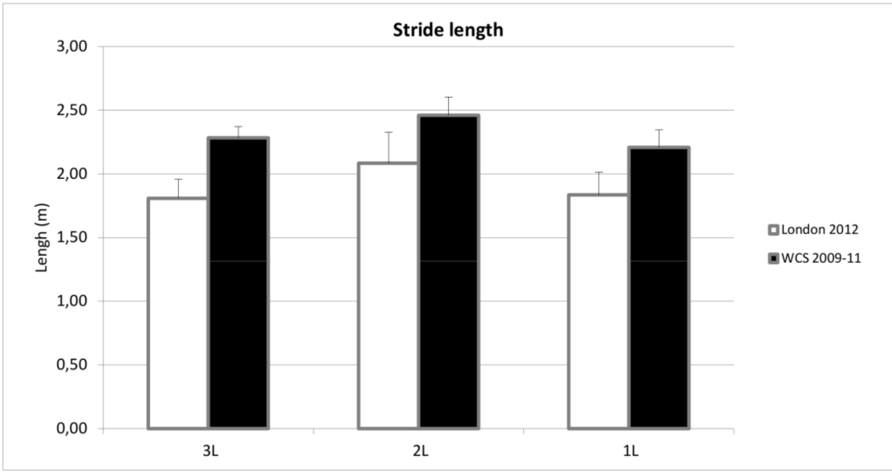

FIGURE 3: Length in the three last strides (London 2012).

When studying F42 and F44 athletes separately, there are major differences in the stride length, especially in LS_3 and LS_1, which shows a significant difference ($p<0.05$). The effect sizes measure with Coen's δ in the last three steps are 3,80, 1,93 and 2,29 respectively. Class F44 athletes have a larger average stride length. It is worth mentioning here that when these data were analysed the change in foot support, with or without prosthesis, has not been taken into account.

Stride frequency

The average frequency of each of the last three values in the London group were 4.53±0.72Hz, 3.90±0.64Hz and 5.24±0.54Hz, respectively. Since these particular values have not been referred to in any studies, this is the reason why stride frequency for the Berlin group has been calculated using the stride length and velocity data. The resulting average values were 4.54±0.17Hz, 4.31±0.26Hz and 4.73±0.31Hz, showing that the frequency pattern in the Berlin group is lower in the penultimate stride and higher in the last, although the differences between both values are smaller. Relative difference in frequency has also been calculated comparing LS_3/LS_2, and LS_2/LS_1. In the London group there was a decrease (-12.8±14.6%) followed by a high increase (36.7±20.1%) respectively. When comparing the changes in the Berlin group, differences are less, with values of -5.04±5.14% and 9.88±9.49%, respectively. There were only two athletes that did not follow this trend. When the rest of the group shows negative values, theirs are positive and vice versa.

When analysing the stride frequency of classes F42 and F44 separately, no major differences are found in LS_3 (4.51±0.96Hz and 4.53±0.53Hz, respectively). Values increase for LS_2 (3.69±0.82Hz and 4.07±0.45Hz, respectively) and LS_1 (5,04±0.76Hz and 5.39±0.22Hz, respectively). There are no significant differences between F42 and F44 athletes for the relative stride frequency value.

Conclusions

The results obtained in the present study suggest that despite the obvious performance differences, there are a wide range of similarities in the biomechanical patterns in the long jump event between the para- athletes with limb deficiency at the London 2012 Paralympic Games and the high-level able-bodied athletes. The jump distances achieved by able-bodied athletes are usually longer than those achieved by amputee athletes. Below-the-knee amputee athletes (F44), 6.30±0.58m, can generally achieve longer jumping distances than above-the-knee amputee athletes (F42), 5.28±1.03m.

There is a significant correlation between the BCM velocity at X-axis and the jumping distance; the higher the former, the longer the latter. An increase in the BCM velocity at X-axis at the time of take-off for the last three strides of 0.1m/s can help improve the official jumping distance by 0.11m.

The stride pattern of the last three strides used by the athletes in the London group is clearly medium-long-short, with average values of 1.81±0.15m, 2.08±0.24m and 1.84±0.18m, following the pattern of high-level able-bodied athletes.

The average instantaneous horizontal velocity in the last three strides is 8.03m/s, 8.07m/s and 8.37m/s, respectively. This means that the last stride is the fastest, which differs from results obtained in previous research with high-level able-bodied athletes, where there is a loss of velocity in the last stride.

The stride frequency pattern of each of the last three strides is high-low-high, the same pattern that the analysed high-level able-bodied athletes use, although there are major differences amongst the studied Paralympic athletes. When observing class F42 and F44 athletes separately, there are no major differences in LS_3, whereas differences are greater in LS_2 and LS_1.

Among the nine athletes using a prosthesis, seven of them (77.8%) performed take-off with their prosthetic leg, thus achieving better results both in D_{OFF} and D_{EFF} (6.03±0.91m and 6.21±0.72m, respectively), than those who performed the take-off leaning on their non-prosthetic limb (n=4) (5.50±1.00m and 5.57±0.94m). If we use the current IPC classification, and we only value athletes with prostheses, categories T64 T63, the resulting DOFF and DEFF of the take-off leaning on their non-prosthetic limb (n=2) is 4.81± 1,06m and 4.91±0,95m.

We can then conclude that leaning on the prosthetic leg at take-off improves the athletes' performance. This fact indicates a clear change in the trend from past Paralympic Games (Nolan & Lees, 2000).

Summarising, the findings concluded from this study, may have an impact on clinical practice in the near future by improving prosthetic take-off training and adapting the prosthesis to the conditions required by the take-off impact.

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