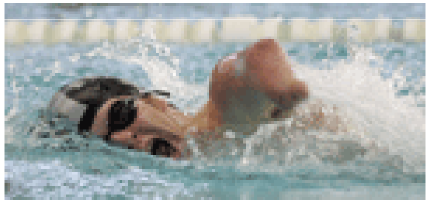
PARALYMPIC SPORTS, THE NEXT FRONTIER FOR SPORTS SCIENCE










Justin Keogh PhD

SPORTS PERFORMANCE
RESEARCH INSTITUTE, NEW ZEALAND
AN INSTITUTE OF AUT UNIVERSITY

PARALYMPICS NEW ZEALAND

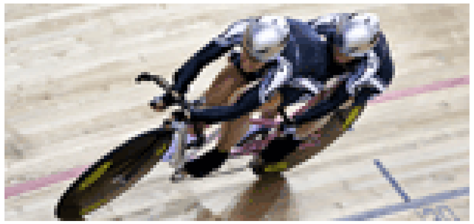
AUT UNIVERSITY SPORT+ RECREATION

Overview

- History of Paralympic sport
- Athlete eligibility and classification
- Effects on Locomotion
  - Running and jumping
  - Swimming
  - Wheelchair
- Projecting External Objects
  - Track & field throws
  - Powerlifting
- Evolution of sports performance
- Training practices
- Applications of research
- Future research directions

History

- Organised sport for athletes with disability started in 1948 in Stoke Mandeville, England (Bailey, 2008)
- Over the last 7 decades, a number of organisations formed
- IPC organised the Paralympic Games every 4 yrs
- 2008 Beijing Paralympic Games had 20 sports and 3951 athletes from 146 countries (IPC, 2009)



Classification & Eligibility

- At Beijing in 2008, classifications groups included spinal injury, amputee, visually impaired, cerebral palsy and les autres (IPC, 2009).
- Much within- and between class heterogeneity of athletes exists
  - Ongoing debate exists on how they should best be classified so to ensure fair competition (Jones and Wilson, 2009; Burkett, 2010; Tweedy and Vanlandewijck, in press).
  - Structural vs Functional approaches

Locomotion

- Paralympic athletes compete in sports where they need to move quickly when:
  - Running
  - Swimming
  - Cycling (leg- or arm-propelled)
  - Pushing a wheelchair.
- Following section will examine the findings of some selected studies that examined the biomechanics of Paralympic running, jumping, swimming and wheelchair propulsion.

Running

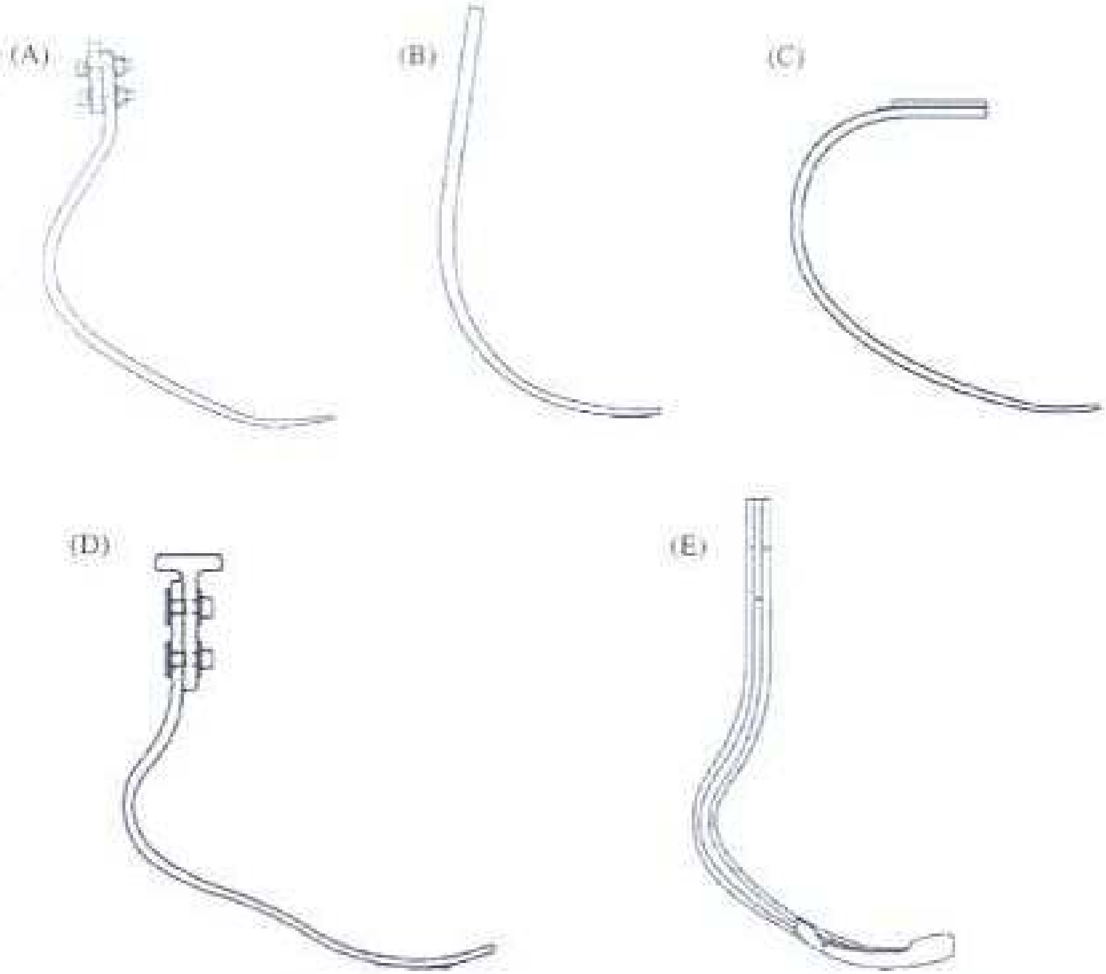


Fig. 2. The different sprint foot designs: (A) Cheetah (Össur), (B) flex-sprint (Össur), (C) flex-run (Össur), (D) sprinter (Otto Bock), and (E) C-sprint (Otto Bock).

Nolan (2008) *Foot Ankle Surg*

Running

- Debate has raged about benefits of prosthetic limbs since Oscar Pistorius attempted to qualify for 2008 Beijing Olympics Games
- Metabolic cost of running, sprinting endurance and running mechanics were examined in trans-tibial sprinter
  - Compared to data from the literature and 400 m able-bodied sprinters of similar anthropometric and performance levels

Weyand et al. (2009) *J Appl Physiol*

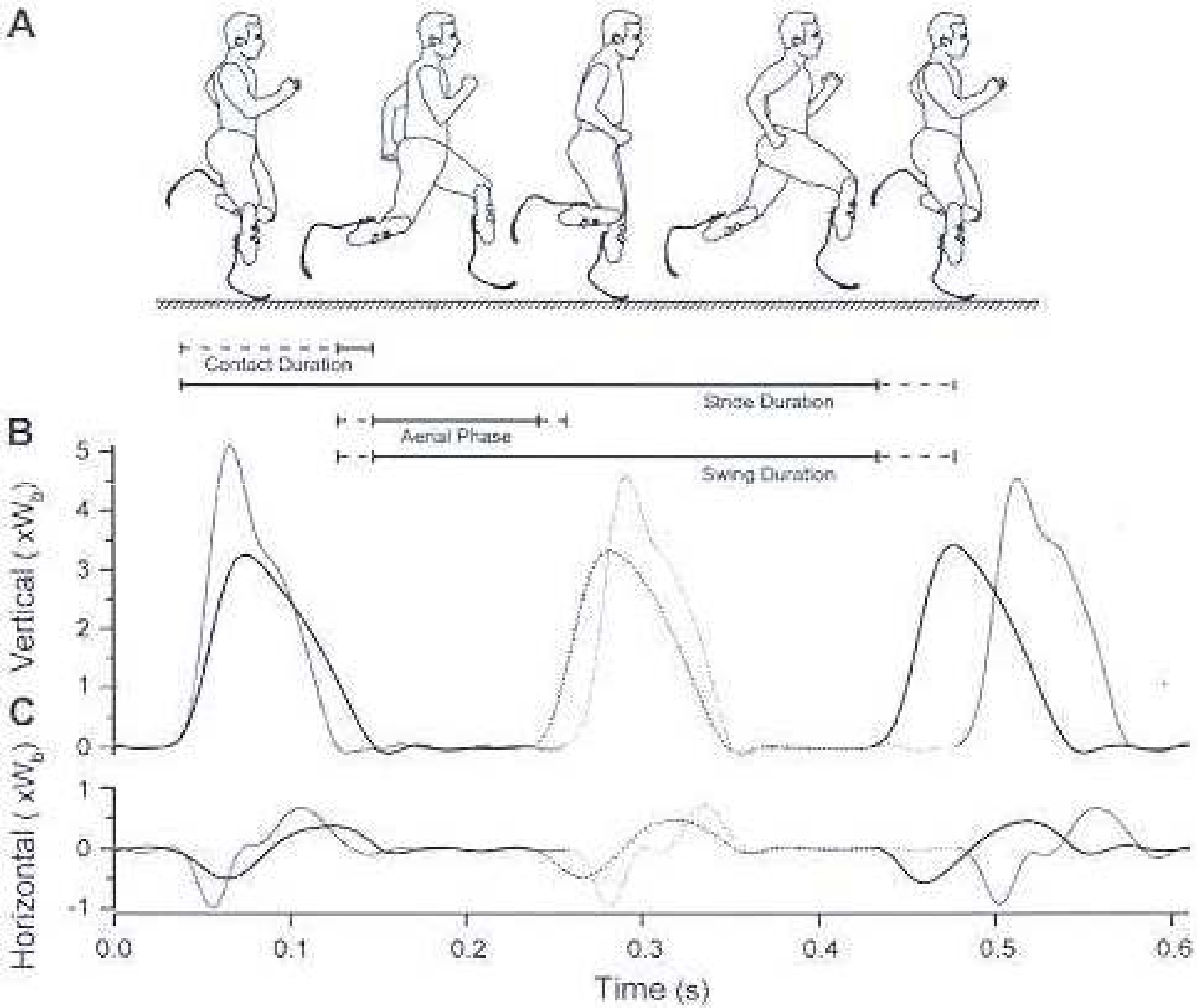


Fig. 1. *A*: tracings from video images of our amputee subject during the contact, aerial, and swing phases of a stride while sprinting on a treadmill at 10.5 m/s. Also shown are the vertical (*B*) and horizontal ground reaction forces, normalized to body weight (*C*) vs. time for our amputee and an intact-limb subject at a treadmill speed of 10.5 m/s. Black (amputee sprinter) and gray lines (intact-limb sprinter) illustrate the ground reaction force traces of the right (solid) and left limbs (dotted) of the 2 subjects. Differences in the duration of the aerial, swing, and total stride times (shorter) for our amputee vs. intact-limb subject correspond to the dashed line extensions of the respective lines in *A* (*bottom*); differences in the duration of the contact time (longer) for our amputee vs. intact-limb subject correspond to the solid line extensions.

Weyand et al. (2009) *J Appl Physiol*

Table 1. *Sprinting mechanics*

Measure	10.0 m/s	Top Speed
Time of contact, s		
Intact limb sprinters	0.099 (0.004)	0.094 (0.008)
Amputee sprinter	0.113	0.107
Difference (× SD)	+3.5	+1.7
Percent difference	+14.1	+14.2
Swing time, s		
Intact limb sprinters	0.371 (0.022)	0.359 (0.019)
Amputee sprinter	0.293	0.284
Difference (× SD)	−3.5	−4.0
Percent difference	−21.0	−21.0
Aerial time, s		
Intact limb sprinters	0.140 (0.011)	0.136 (0.011)
Amputee sprinter	0.092	0.090
Difference (× SD)	−4.4	−4.3
Percent difference	−34.5	−34.4
Stance average vertical force (× Wb)		
Intact limb sprinters	2.32 (0.10)	2.30 (0.13)
Amputee sprinter	1.79	1.84
Difference (× SD)	−5.2	−3.6
Percent difference	−22.9	−21.7
Peak vertical force (× Wb)		
Intact limb sprinters	3.72 (0.31)	3.93 (0.51)
Amputee sprinter	3.24	3.38
Difference (× SD)	−1.5	−1.1
Percent difference	−12.8	−14.0

Values are means and SD (in parentheses) for $n = 4$ intact-limb sprinters. Top speeds of our amputee and intact-limb sprinters were 10.8 and 10.8 (SD 0.6) m/s, respectively. Top speed: stride length = 4.22 vs. 4.86 (SD 0.27) m; stride frequency = 2.56 vs. 2.21 (SD 0.08) Hz; 10.0 m/s: stride length = 4.06 vs. 4.73 (SD 0.19) m; stride frequency = 2.46 vs. 2.11 (SD 0.089) Hz. Forces are expressed as multiples of body weight ($\times W_b$).

Weyand et al. (2009)
J Appl Physiol

Jumping

- Examined changes in kinematics during last few strides before long jump take-off
  - Six male unilateral trans-femoral and seven male unilateral trans-tibial amputees competing in a World Championships final
  - Filmed in the sagittal plane using a 100-Hz digital video camera

Nolan & Lees (2007) *J Sports Sci*

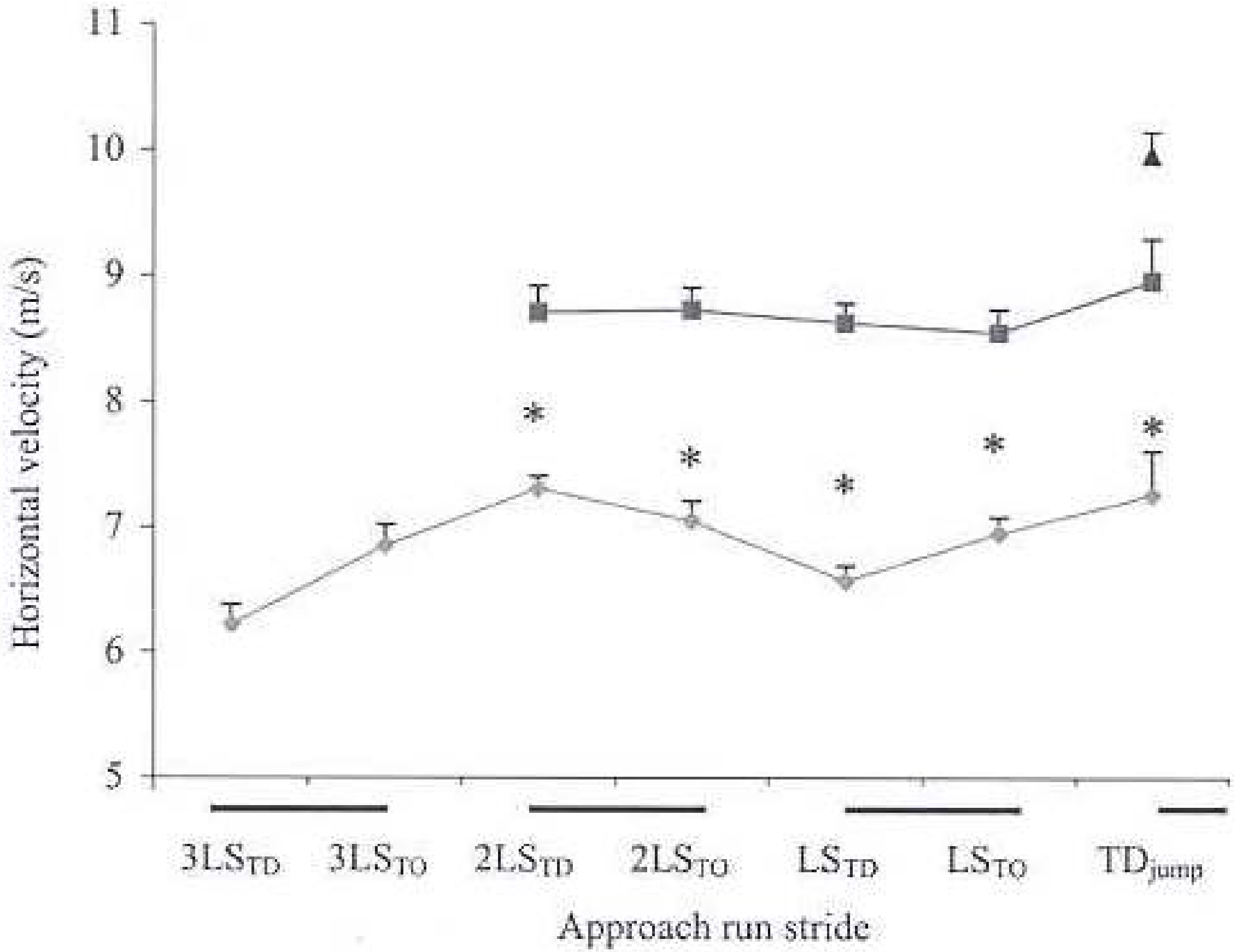


Figure 1. Horizontal velocity of the centre of mass at touch-down (TD) and take-off (TO) for the last few strides on the approach run (3*LS* = third last stride, 2*LS* = second last stride, *LS* = last stride, TD_{jump} = touch-down on the take-off board) for trans-femoral (♦) and trans-tibial (■) amputees (▲, Lees *et al.*, 1994). The solid line (—) indicates when the foot is in contact with the ground. *Significant ($P < 0.05$) difference in velocity between trans-femoral and trans-tibial amputees.

Nolan & Lees (2007) *J Sports Sci*

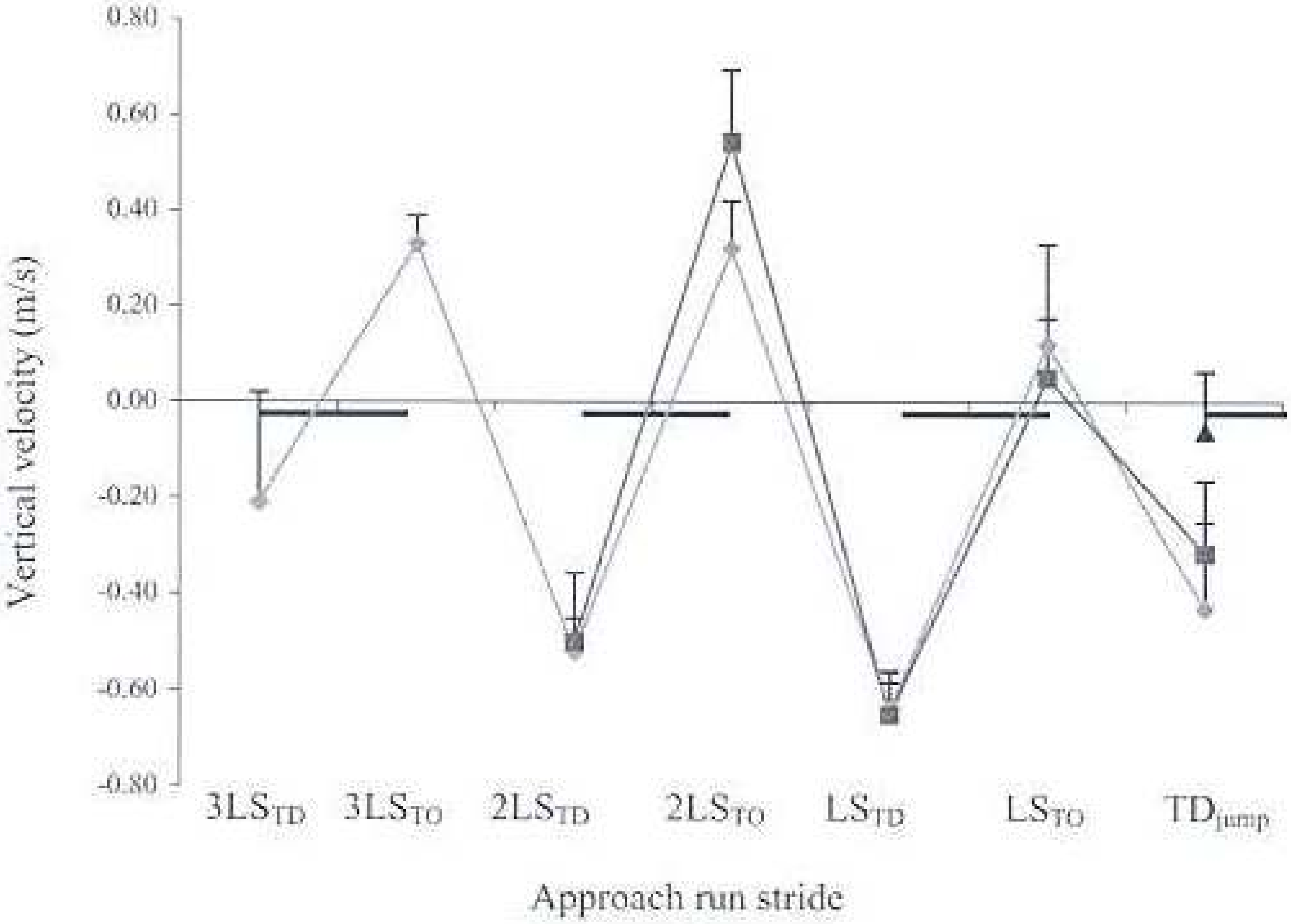


Figure 2. Vertical velocity of the centre of mass at touch-down (TD) and take-off (TO) for the last few strides on the approach run (3LS = third last stride, 2LS = second last stride, LS = last stride, TD_{jump} = touch-down on the take-off board) for trans-femoral (♦) and trans-tibial (■) amputees (▲, Lees *et al.*, 1994). The solid line (—) indicates when the foot is in contact with the ground.

Nolan & Lees (2007) *J Sports Sci*

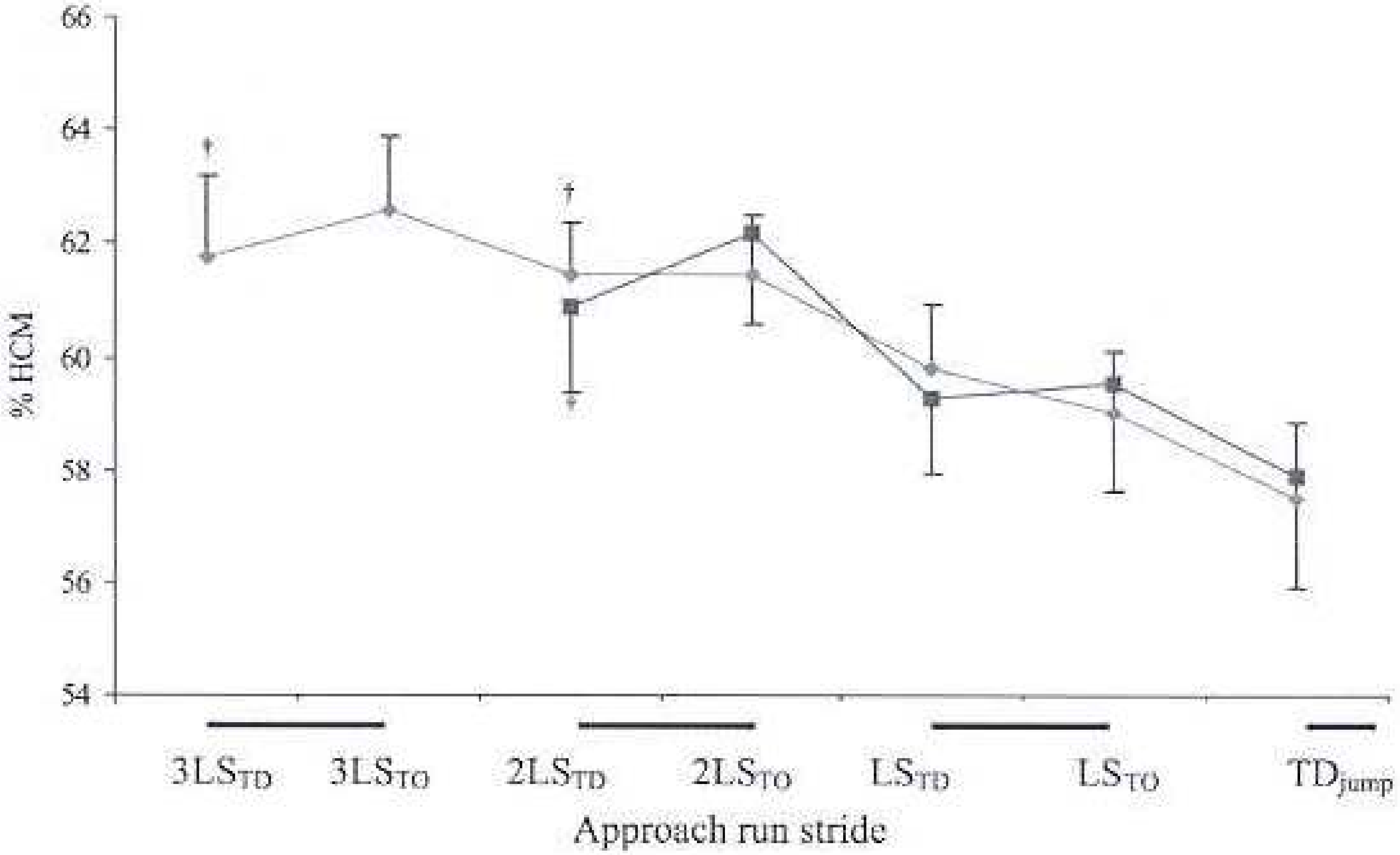


Figure 3. Height of the centre of mass normalized to individual estimated height (%HCM) at touch-down (TD) and take-off (TO) for the last few strides on the approach run (3LS = third last stride, 2LS = second last stride, LS = last stride, TD_{jump} = touch-down on the take-off board) for trans-femoral (♦) and trans-tibial (■) amputees. The solid line (—) indicates when the foot is in contact with the ground. †Significant ($P < 0.05$) difference in height from touch-down on the take-off board.

Nolan & Lees (2007) *J Sports Sci*

Table II. Mean lengths (m) of the third last, second last and last strides of trans-femoral and trans-tibial (TT) amputees on the approach run (standard deviations in parentheses).

	Third last stride	Second last stride	Last stride
Trans-femoral	1.58# (0.17)	1.83~‡ (0.20)	1.66*# (0.16)
Trans-tibial		2.08~ (0.16)	2.09* (0.27)

*Significant difference between trans-tibial and trans-femoral amputees. ~Trend towards a difference between trans-tibial and trans-femoral amputees. ‡Trend towards a difference from the last stride. #Trend towards a difference from the second last stride.

Nolan & Lees (2007) *J Sports Sci*

Table III. Mean durations (s) of the third last, second last and last strides of trans-femoral and trans-tibial amputees on the approach run (standard deviations in parentheses).

	Third last stride	Second last stride	Last stride
Trans-femoral	0.11 (0.01)	0.13[‡] (0.02)	0.11 (0.01)
Trans-tibial		0.12 (0.01)	0.12 (0.02)

[‡]Trend towards a difference from the last stride.

Nolan & Lees (2007) *J Sports Sci*

Swimming

- Examined relationships between swimming speed, stroke length and stroke frequency with anthropometric characteristics
- Thirteen highly trained single arm amputee swimmers (3 male, 10 female)
- Underwater filming from a lateral view during seven increasingly faster 25-m freestyle trials.

Osborough et al. (2009) *J Appl Biomech*

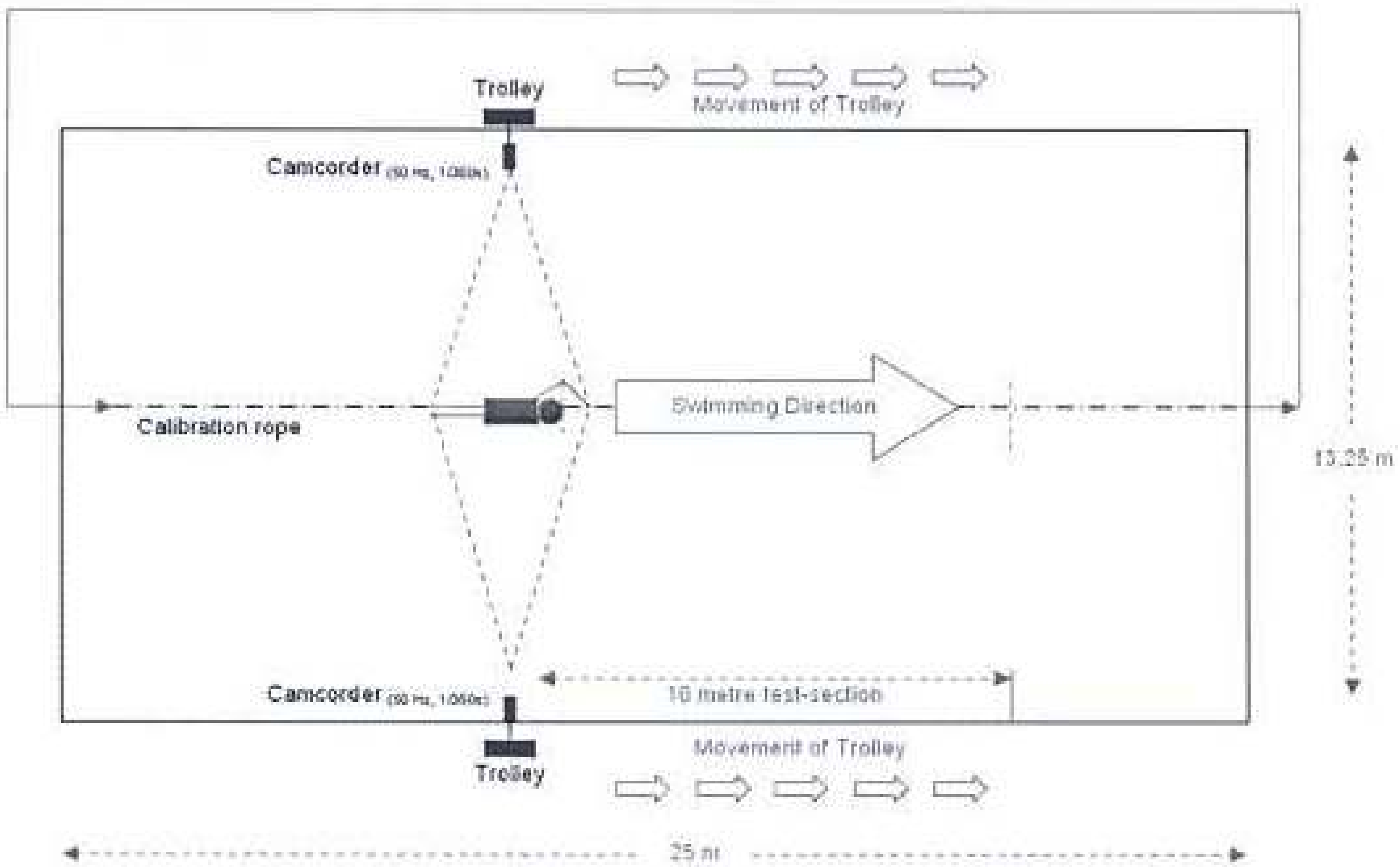


Figure 1 — Experimental setup of the swimming test protocol and video recording procedure.

Osborough et al. (2009) *J Appl Biomech*

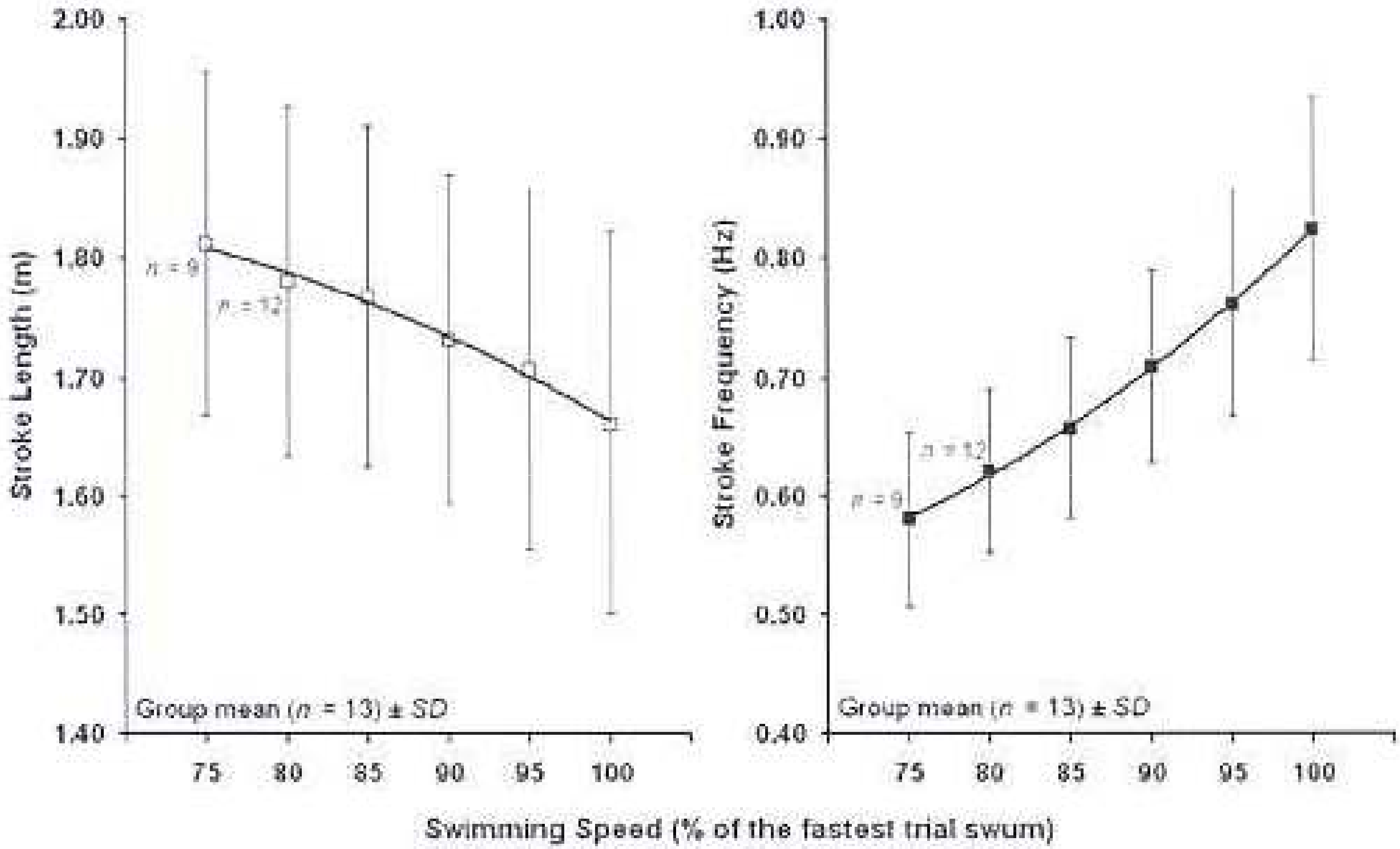


Figure 2 — Changes in SL and SF (mean ± *SD*) with an increase in swimming speed (expressed as a percentage of the maximum swimming speed recorded).

Osborough et al. (2009) *J Appl Biomech*

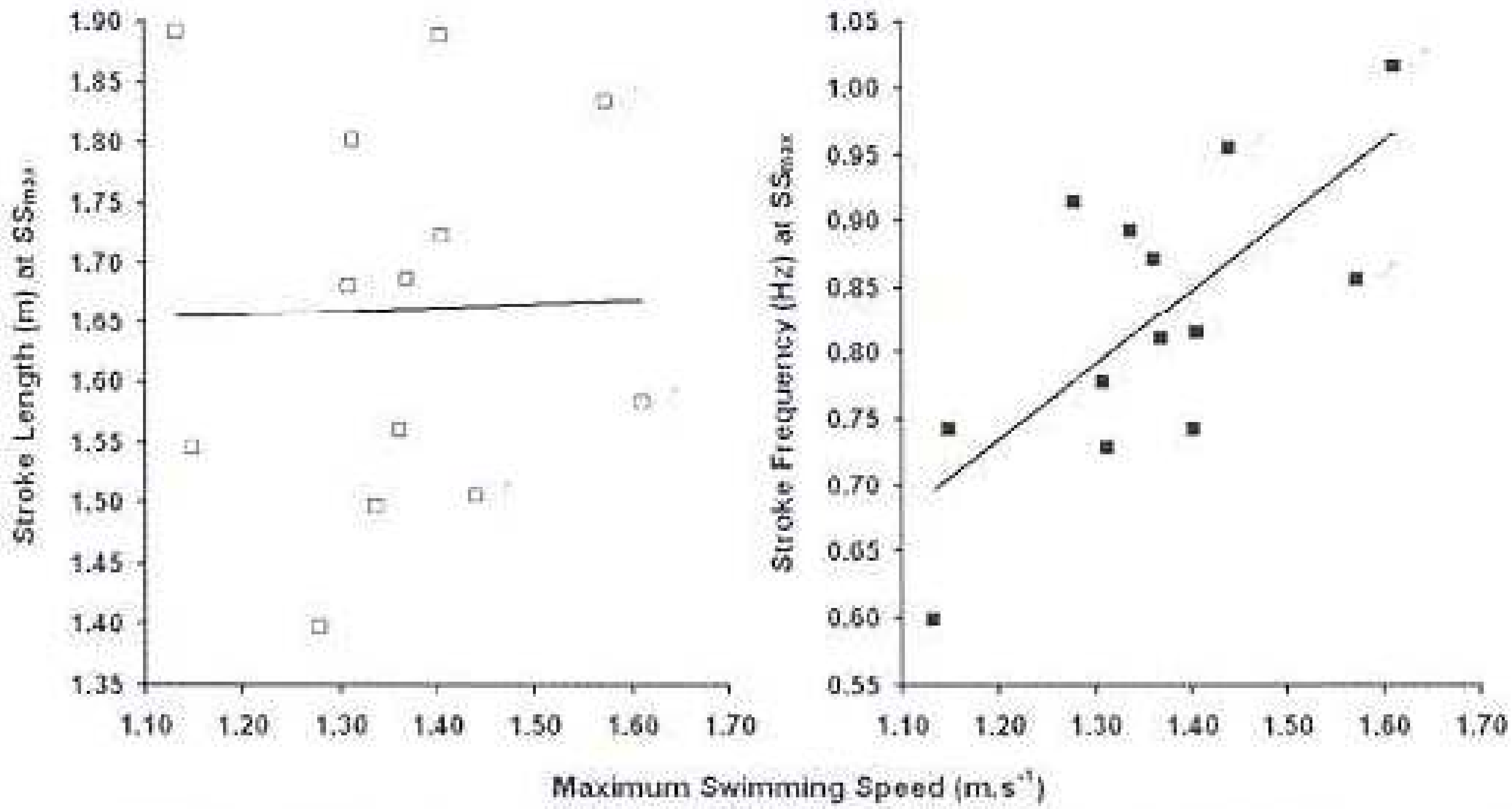


Figure 3 — Interswimmer correlations. Left-hand side: SL_{SSmax} versus SS_{max} (r = .01). Right-hand side: SF_{SSmax} versus SS_{max} (r = .72; p < .01).

Osborough et al. (2009) *J Appl Biomech*

Anthropometric Correlations

- Stroke frequency at maximum swim speed significantly correlated to:
  - Biacromial breadth ($r = 0.86$)
  - Shoulder girth ($r = 0.64$)
  - Upper arm length ($r = 0.58$)

- No significant correlations between anthropometry and stroke length

Osborough et al. (2009) *J Appl Biomech*

Wheelchair propulsion

- Very common form of locomotion:
  - Athletic events from 100 m up to the marathon
  - Many ball sports
  - Many athletes also use for day-day movements

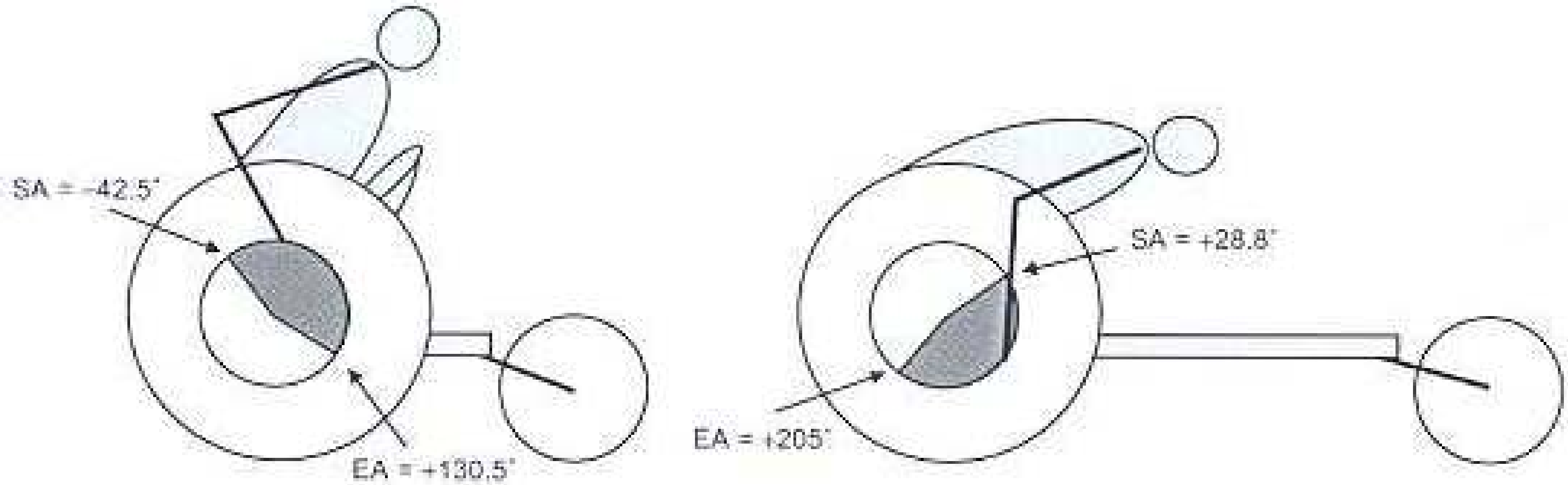


Fig. 4. Wheelchair configuration and seat position influencing the orientation of the push angle. Left: orientation in 1986 according to Higgs[69]; right: orientation in 1995 according to Wang et al.[70]. **EA** = end angle; **SA** = start angle.

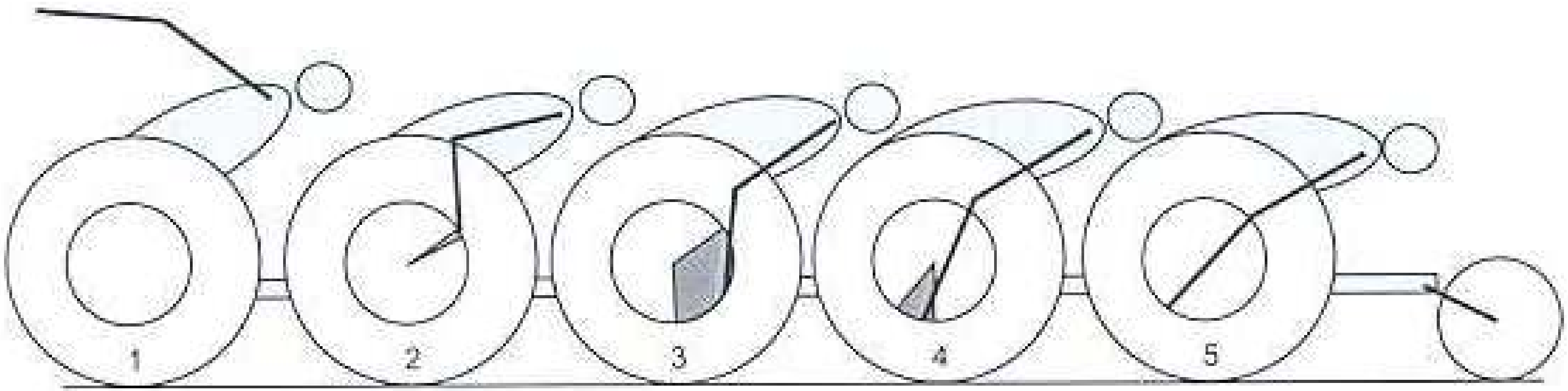


Fig. 5. Wheelchair racing propulsion technique. **1** to **2** = acceleration phase; **2** = impact energy transfer phase; **3** = drive phase; **4** = rotation force production phase; **5** = disengagement phase; **5** to **1** = back swing.

Vanlandewijck et al. (2001) *Sports Med*

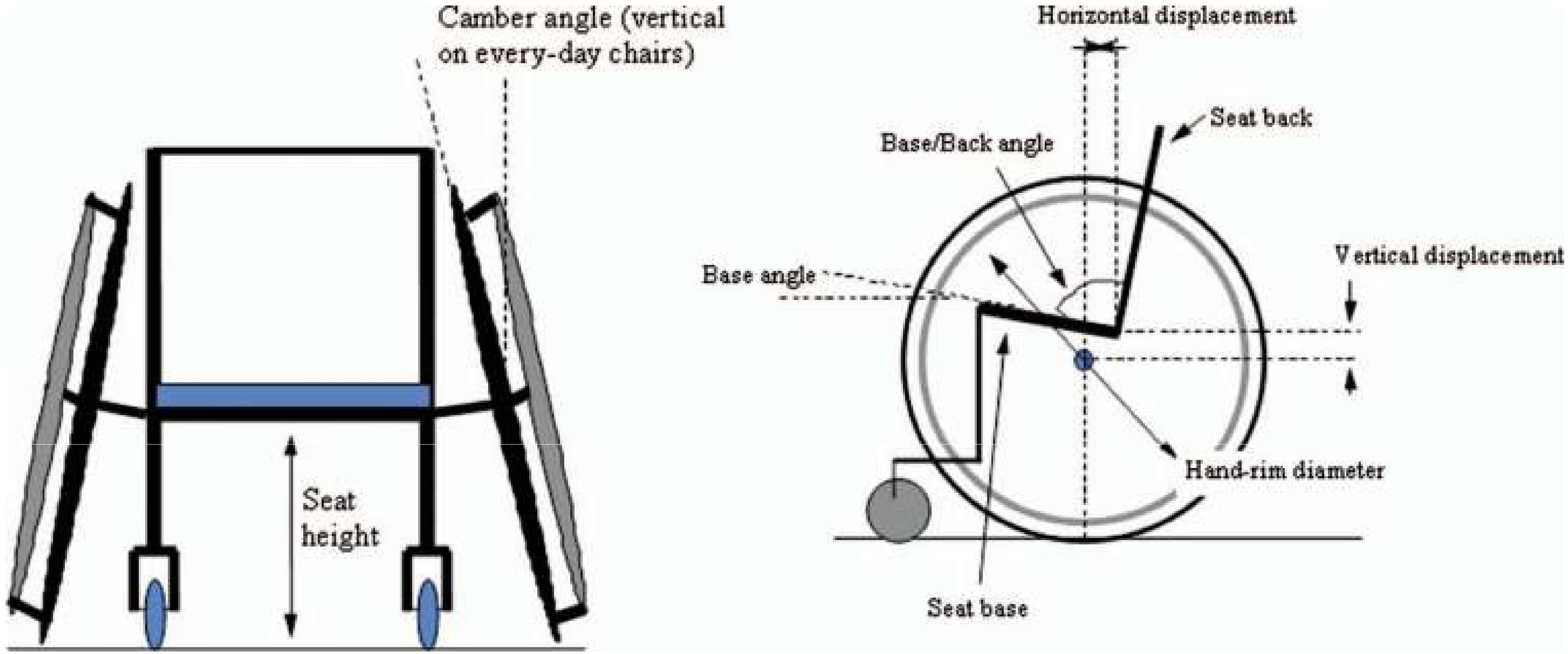


Figure 7. Characteristics of a wheelchair viewed from both the frontal and sagittal plane.

Goosey-Tolfrey (in press) *Disabil Rehabil*

100 m Wheelchair Sprints

- Six T4 and four T3 wheelchair sprinters
- Performed two 100 m sprints
- Acceleration, maximum speed and deceleration phases examined

Chow & Chae (2007) *J Biomech*

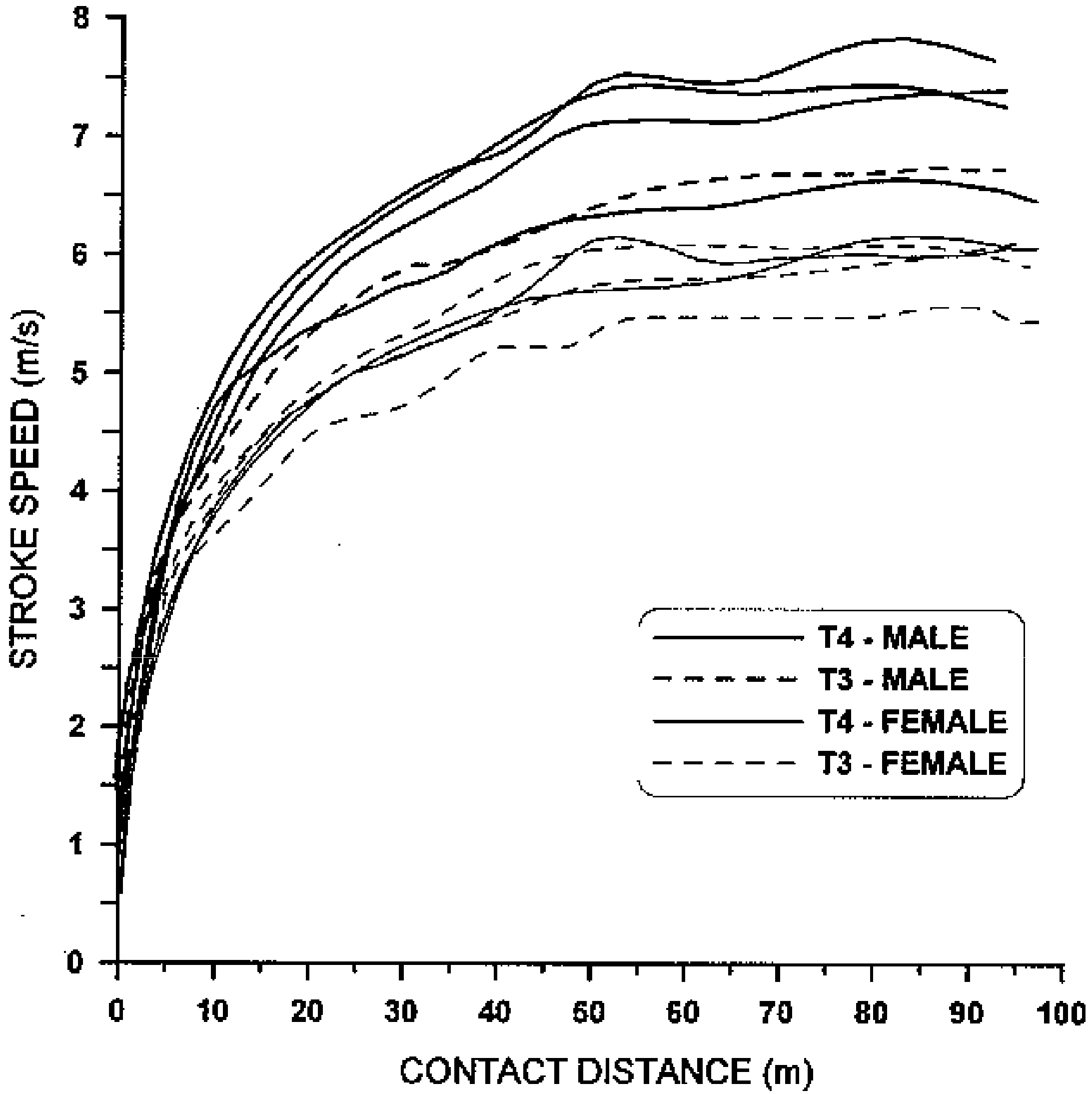


Fig. 3. Speed profiles of individual participants during a 100-m race.

Chow & Chae (2007) *J Biomech*

100 m Wheelchair Sprints

- With increased velocity:
  - Increased stroke length
  - No real change in stroke frequency / time
  - Reduced push time

- 100 m time correlated to:
  - Maximum speed ($r = -0.982$)
  - Acceleration duration ($r = 0.649$)

Chow & Chae (2007) *J Biomech*

Wheelchair Velocity Profile

- Case study involving one elite T4 wheelchair 100-400 m sprinter
- Performed 8 x ~10 m sprints
- 100 Hz video analysis and velocometer used
- Examined push and recovery phases as well as HAT movements

Moss et al. (2005) *J Biomech*

Table 1
Mean propulsive cycle data for the first six pushes of the sprint start calculated from eight trials

Push	Propulsion phase (s)	Recovery phase (s)	Push durations (s)	Contact angle (°)	Release angle (°)	Range (°)
P1	0.62±0.02	0.20±0.01	0.82±0.02	65±5	−5±14	70±11
% Cycle time	76±1	24±1				
P2	0.33±0.01	0.19±0.01	0.52±0.01	72±12	−27±9	99±19
% Cycle time	63±1	37±1				
P3	0.28±0.01	0.21±0.01	0.49±0.01	75±13	−42±5	117±15
% Cycle time	57±1	43±1				
P4	0.24±0.01	0.23±0.01	0.47±0.02	81±8	−43±15	124±15
% Cycle time	52±2	48±2				
P5	0.21±0.01	0.24±0.01	0.45±0.01	80±11	−46±29	125±27
% Cycle time	47±2	53 ± 2				
P6	0.21±0.01	0.24±0.02	0.45±0.01	83±12	−50±21	133±27
% Cycle time	47±3	53±3				

Table 2
Mean velocity data for the first six pushes of the sprint start calculated from eight trials

Push	Velocity at contact ($m\,s^{-1}$)	Velocity at release ($m\,s^{-1}$)	Peak velocity ($m\,s^{-1}$)	Time of peak velocity (relative to contact) (s)
P1	0	1.5±0.1	1.6±0.1	0.65±0.04
P2	1.2±0.0	2.4±0.1	2.5±0.1	0.37±0.01
P3	2.0±0.0	3.0±0.1	3.1±0.1	0.32±0.00
P4	2.6±0.1	3.5±0.0	3.6±0.1	0.31±0.02
P5	3.1±0.1	3.9±0.1	4.1±0.1	0.28±0.01
P6	3.5±0.1	4.2±0.1	4.4±0.1	0.28±0.01

Moss et al. (2005) *J Biomech*

Wheelchair Velocity Profile – HAT Role

- Peak velocity occurred just after release
- Net momentum of the HAT fluctuates during each stroke
  - Positive momentum during backwards movements
  - Negative momentum during forwards movements
  - Would appear that the backward movement of the HAT after release acts to transfer momentum
- Would suggest that over-ground and not stationary wheelchair ergometers used in research and sports science consultancy

Moss et al. (2005) *J Biomech*

Wheelchair propulsion

- Compare the velocity of wheelchair propulsion with and without the use of a tennis racquet
  - Eight male wheelchair tennis players performed a series of 20m sprints from a stationary start
  - Velocometer used to record changes in velocity

Goosey-Tolfrey & Moss (2005) *Adapt Phys Activity Quart*

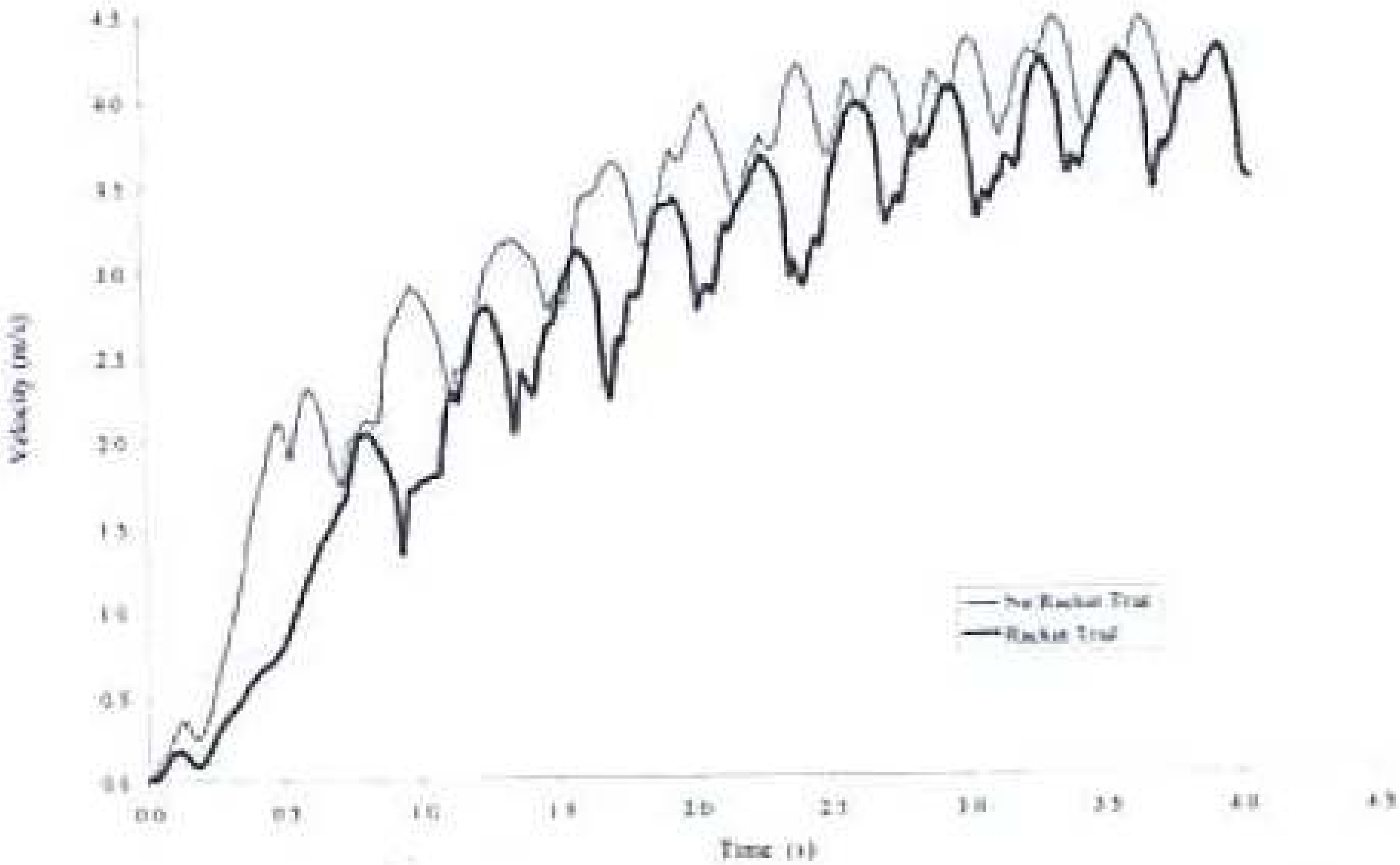


Figure 1 — Wheelchair velocity versus time plot of propulsion with and without a tennis racquet (solid line indicates the R condition). Example taken from participant number 5.

Goosey-Tolfrey & Moss (2005) *Adapt Phys Activity Quart*

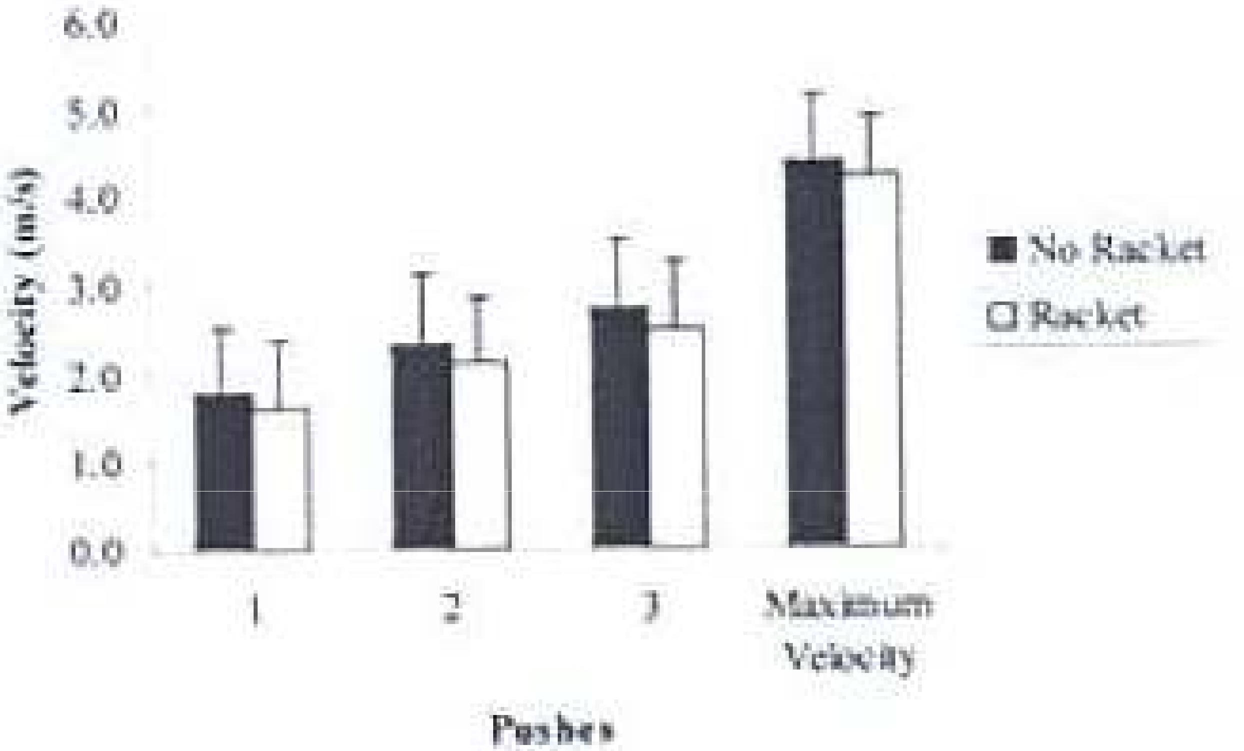


Figure 2 — A comparison between the wheelchair velocities of the first three pushes and peak velocity with (R) and without (NR) the tennis racquet. The NR condition resulted in significantly higher velocities than the R condition ($p < 0.01$). Effect sizes range from 0.17 to 0.30.

Goosey-Tolfrey & Moss (2005) *Adapt Phys Activity Quart*

Projecting External Objects

- 3-D kinematics of the shot put and upper body segments at the instant of release and during the forward thrust were determined.
  - Relationships to athlete's medical classification and performance were examined
- 17 male shot putters of different classes
- Each participant performed six trials and the best trial was selected for analysis

Chow et al. (2000) *J Sports Sci*

Table 1. Putter information

Putter no.	Classification	Body mass (kg)	Age (years)	Standard[a]	Personal best[b] (m)	Throw analysed (m)
1	F2	100.0	31	Elite	7.8	5.24
2	F2	72.7	25	Elite	-	3.93
3	F3	95.5	33	Elite	5.9	5.23
4	F4	77.3	47	Emerging	9.33	7.21
5	F4	77.5	37	Elite	8.09	7.26
6	F4	100.0	22	Emerging	-	6.51
7	F5	107.7	48	Elite	10:20	9.11
8	F5	111.4	26	Emerging	6.96	8.10
9	F5	134.1	51	Elite	7.76	7.46
10	F5	97.7	46	Elite	10.32	8.44
11	F5	127.3	20	Emerging	-	4.29
12	F6	94.5	27	Elite	8.56	7.08
13	F6	54.5	19	Emerging	6.92	6.23
14	F7	105.9	48	Elite	10.78	10.13
15	F7	88.6	30	Emerging	8.10	8.00
16	F7	74.1	44	Elite	9.80	7.34
17	F8	79.5	19	Emerging	-	7.98

[a] Standard rated by Wheelchair Sports, USA.
[b] Best throw recorded in official competitions.

Chow et al. (2000) *J Sports Sci*

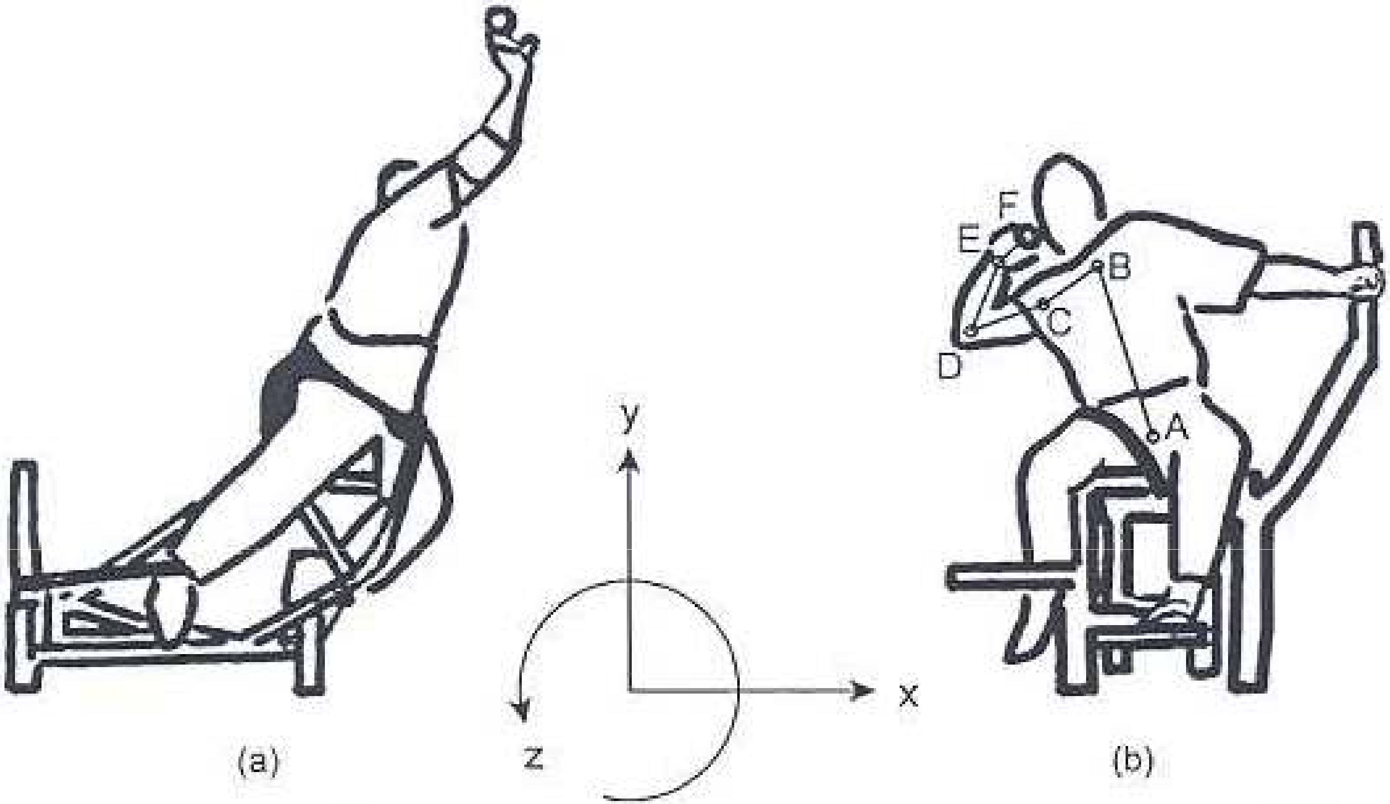


Fig. 1. The chair used by an athlete must be located inside the circle but the footrest(s) or part of the legs can protrude outside the circle (a). Some athletes of the lower classes hold on to the chair or a pole that is fixed to the chair for additional support during the puts (b). The segmental model used in this study is defined by the mid-hips (A), mid-shoulders (B), right shoulder (C), right elbow (D), right wrist (E) and third knuckle of the right hand (F).

Chow et al. (2000) *J Sports Sci*

Table 2. Selected characteristics of the shot at the instant of release (mean ± s)

	Classification						
	F2 (n = 2)	F3 (n = 1)	F4 (n = 3)	F5 (n = 5)	F6 (n = 2)	F7 (n = 3)	F8 (n = 1)
Speed of release ($m \cdot s^{-1}$)							
horizontal	4.8 ± 0.1	5.6 ± 0.0	6.0 ± 0.2	6.5 ± 1.0	6.6 ± 0.1	6.4 ± 1.1	6.4 ± 0.0
vertical	2.0 ± 1.5	2.2 ± 0.0	3.6 ± 0.3	3.5 ± 1.0	3.2 ± 1.2	4.3 ± 0.4	3.9 ± 0.0
resultant	5.3 ± 0.6	6.0 ± 0.0	6.9 ± 0.3	7.4 ± 1.2	7.4 ± 0.5	7.8 ± 1.1	7.5 ± 0.0
Angle of release (°)	19.8 ± 13.7	22.2 ± 0.0	29.8 ± 2.3	27.1 ± 6.6	23.8 ± 6.8	33.7 ± 2.1	29.3 ± 0.0
Optimum angle (°)	33.3 ± 2.3	33.8 ± 0.0	36.3 ± 0.6	36.7 ± 1.8	36.9 ± 0.7	36.9 ± 1.5	36.7 ± 0.0
Angle difference (°)[a]	−13.5 ± 11.3	−11.6 ± 0.0	−6.5 ± 1.8	−9.6 ± 6.5	−13.1 ± 6.1	−3.2 ± 3.6	−7.4 ± 0.0

[a] A negative value indicates that the angle of release is smaller than the optimal angle.

Chow et al. (2000) *J Sports Sci*

Table 6. Spearman rank-order correlation coefficients

Variable	Classification	Measured distance
Shot at release		
Angle of release	0.35	0.52*
Height of release	0.62**	0.79***
Forward location relative to seat front	0.22	0.10
Location relative to right shoulder		
forward	−0.10	−0.42
vertical	0.32	0.49*
lateral	0.28	0.26
Location relative to left shoulder		
forward	0.12	0.03
vertical	0.43	0.64**
lateral	0.24	0.10

Significant at: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Chow et al. (2000) *J Sports Sci*

Body segment at release		
Inclination		
trunk	0.07	−0.04
shoulder girdle	0.26	0.39
upper arm	0.57*	0.22
forearm	0.02	0.43
hand	−0.03	0.08
Angular speed		
trunk	0.42	0.18
shoulder girdle	0.47	0.48
upper arm	0.64**	0.76***
forearm	−0.39	−0.08
hand	0.36	0.50*
Range of motion during the delivery		
Trunk	0.06	0.30
Shoulder girdle	0.53*	0.55*
Upper arm	0.64**	0.41
Forearm	0.11	0.07
Hand	0.18	0.19
Average angular speed during the delivery		
Trunk	0.66**	0.57*
Shoulder girdle	0.66**	0.69**
Upper arm	0.75***	0.61**
Forearm	0.53*	0.46
Hand	0.38	0.37

Significant at: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Chow et al. (2000) *J Sports Sci*

IPC Powerlifting Records

World Records – Men (as of September 2008)

Event	Athlete	NPC	Result	City of Competition	Date of Competition
Up to 48.00kg	ISHAKU Ruel	NGR	169.00 kg	Beijing	09.09.2008
Up to 52.00kg	JUNG Keum-Jong	KOR	190.00 kg	Sydney	24.10.2000
Up to 56.00kg	OTHMAN Sherif Othman	EGY	202.50 kg	Beijing	11.09.2008
Up to 60.00kg	MOHAMMADI Hamzeh	IRI	203.00 kg	Busan	05.05.2006
Up to 67.50kg	MATHNA Metwaly Ibrahim	EGY	222.50 kg	Busan	05.05.2006
Up to 75.00kg	ZHANG Haidong	CHN	240.00 kg	Sydney	26.10.2000
Up to 82.50kg	ZHANG Haidong	CHN	248.50 kg	Kunming	18.05.2007
Up to 90.00kg	PARK Jong-Chul	KOR	250.00 kg	Busan	30.10.2002
Up to 100.00kg	QI Dong	CHN	247.50 kg	Beijing	16.09.2008
Over 100.00kg	RAJABI GOLOJEH Kazem	IRI	265.00 kg	Beijing	16.09.2008

IPC (2009)
http://www.ipc-powerlifting.org/export/sites/ipc_sports_powerlifting/Records/
2010_03_17IPC_Powerlifting_RecordsxSeniorsx.pdf

IPC Powerlifting Records

World Records - Women (as of September 2008)

Event	Athlete	NPC	Result	City of Competition	Date of Competition
Up to 40.00kg	SOLOVYOVA Lidiya	UKR	105.50 kg	Beijing	09.09.2008
Up to 44.00kg	EJIKE Lucy Ogechukwu	NGR	127.50 kg	Athens	20.09.2004
Up to 48.00kg	EJIKE Lucy Ogechukwu	NGR	130.00 kg	Beijing	10.09.2008
Up to 52.00kg	PEREZ VASQUEZ Amalia	MEX	130.50 kg	Rio de Janeiro	14.08.2007
Up to 56.00kg	OMAR Fatma Omar	EGY	141.50 kg	Beijing	10.09.2008
Up to 60.00kg	BIAN Jianxin	CHN	135.00 kg	Beijing	13.09.2008
Up to 67.50kg	FU Taoying	CHN	145.50 kg	Beijing	13.09.2008
Up to 75.00kg	ZHANG Liping	CHN	145.00 kg	Busan	10.05.2006
Up to 82.50kg	AHMED Heba Said	EGY	155.00 kg	Beijing	14.09.2008
Over 82.50kg	ANOZIE Grace Ebere	NGR	167.50 kg	Kuala Lumpur	05.12.2007

IPC (2009)
http://www.ipc-powerlifting.org/export/sites/ipc_sports_powerlifting/Records/
2010_03_17IPC_Powerlifting_RecordsxSeniorsx.pdf

Evolution of Sports Performance

- 724 official finals times were analysed for 120 male and 122 female swimmers in the 100-m freestyle event at 15 national and international events from 2004-2006.
- Separate analyses were performed for males and females in each of four subgroups:
  - S2–S4, S5–S7, S8–S10 (physical impairment)
  - S11–S13 (visual impairment)
- Mixed modelling of log-transformed times, with adjustment for mean competition times, was used to estimate variability and progression.

Fulton et al. (2009) *J Sports Sci*

Table I. Numbers of races and race times for each Paralympic swimming class (mean ± s).

	Male swimmers		Female swimmers	
Class	Races	Race time (s)	Races	Race time (s)
S2	22	160.9 ± 11.1	13	200.5 ± 14.4
S3	28	127.4 ± 14.5	21	151.7 ± 14.8
S4	18	99.4 ± 10.4	17	114.6 ± 11.7
S5	26	83.2 ± 10.1	24	95.0 ± 10.4
S6	26	74.1 ± 7.9	34	86.9 ± 5.7
S7	38	67.3 ± 3.5	45	82.4 ± 7.9
S8	46	65.7 ± 4.5	37	76.9 ± 6.8
S9	48	60.4 ± 1.8	52	69.4 ± 3.6
S10	42	57.3 ± 2.0	44	66.5 ± 2.5
S11	25	65.9 ± 5.1	21	78.0 ± 4.7
S12	14	57.7 ± 2.2	21	67.3 ± 4.2
S13	28	60.2 ± 3.9	34	66.0 ± 5.3

Note: Class S2–S10 (most through least physically impaired); Class S11–S13 (most through least visually impaired).

Fulton et al. (2009) *J Sports Sci*

Table II. Sample size and effect statistics for within-swimmer race-to-race variability (as a coefficient of variation), race-to-race reproducibility (as an intraclass correlation), and yearly percent progression in the four disability subgroups.

Subgroups[a]	Swimmers	Races per swimmer	Variability[b] (%)	Reproducibility	Progression[b] (% per year)
Males					
S2–S4	25	2.7	3.7 (2.9 to 5.3)	0.82	0.8 (−1.9 to 3.5)
S5–S7	28	3.2	1.2 (0.9 to 1.9)	0.97	0.9 (−0.2 to 1.9)
S8–S10	41	3.3	1.3 (1.1 to 1.7)	0.83	0.5 (−0.1 to 1.0)
S11–S13	26	2.6	2.4 (1.7 to 4.2)	0.77	1.2 (0.0 to 2.3)
Females					
S2–S4	19	2.7	2.9 (2.0 to 5.0)	0.91	−0.8 (−2.7 to 1.1)
S5–S7	36	2.9	2.6 (2.1 to 3.4)	0.81	0.2 (−1.3 to 1.7)
S8–S10	43	3.1	1.7 (1.4 to 2.1)	0.84	0.9 (0.1 to 1.8)
S11–S13	24	3.2	1.5 (1.2 to 2.1)	0.91	0.5 (−0.5 to 1.4)

Notes: [a]Class S2–S10 (most through least physically impaired); Class S11–S13 (most through least visually impaired).
[b]Data in parentheses are 90% confidence intervals.

Fulton et al. (2009) *J Sports Sci*

Training Practices

- Sixteen elite swimmers (9 men and 7 women) who qualified for the 2006 IPC World Champs
- Data grouped by:
  - class (S8, n = 5; S9, n = 3; and S10, n = 4) and
  - disability (cerebral palsy n = 5, arm amputee n = 3, and leg amputee n = 4) for the subgroup of 12
  - Three swimmers who were the sole individuals in their class (S3, S6, and S7) and 1 long distance swimmer (S10) were excluded from this subgroup

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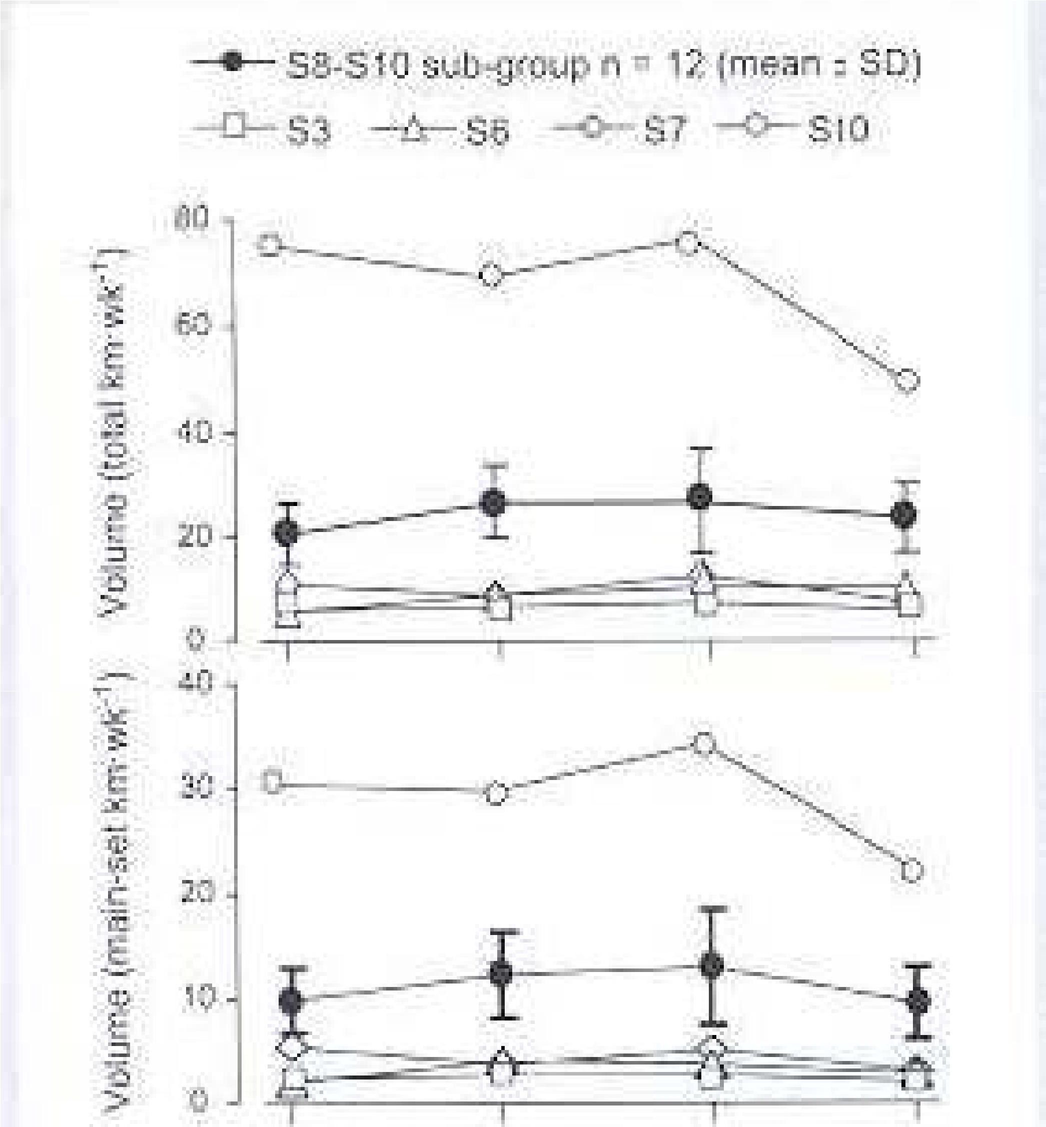

Figure 1. Patterns of training volume and intensity between training phases for the 16-week training block by Paralympic class. Classes S1–S10 represent the swimming classes used in IPC-sanctioned competition as most through least impaired, respectively. IPC = International Paralympic.

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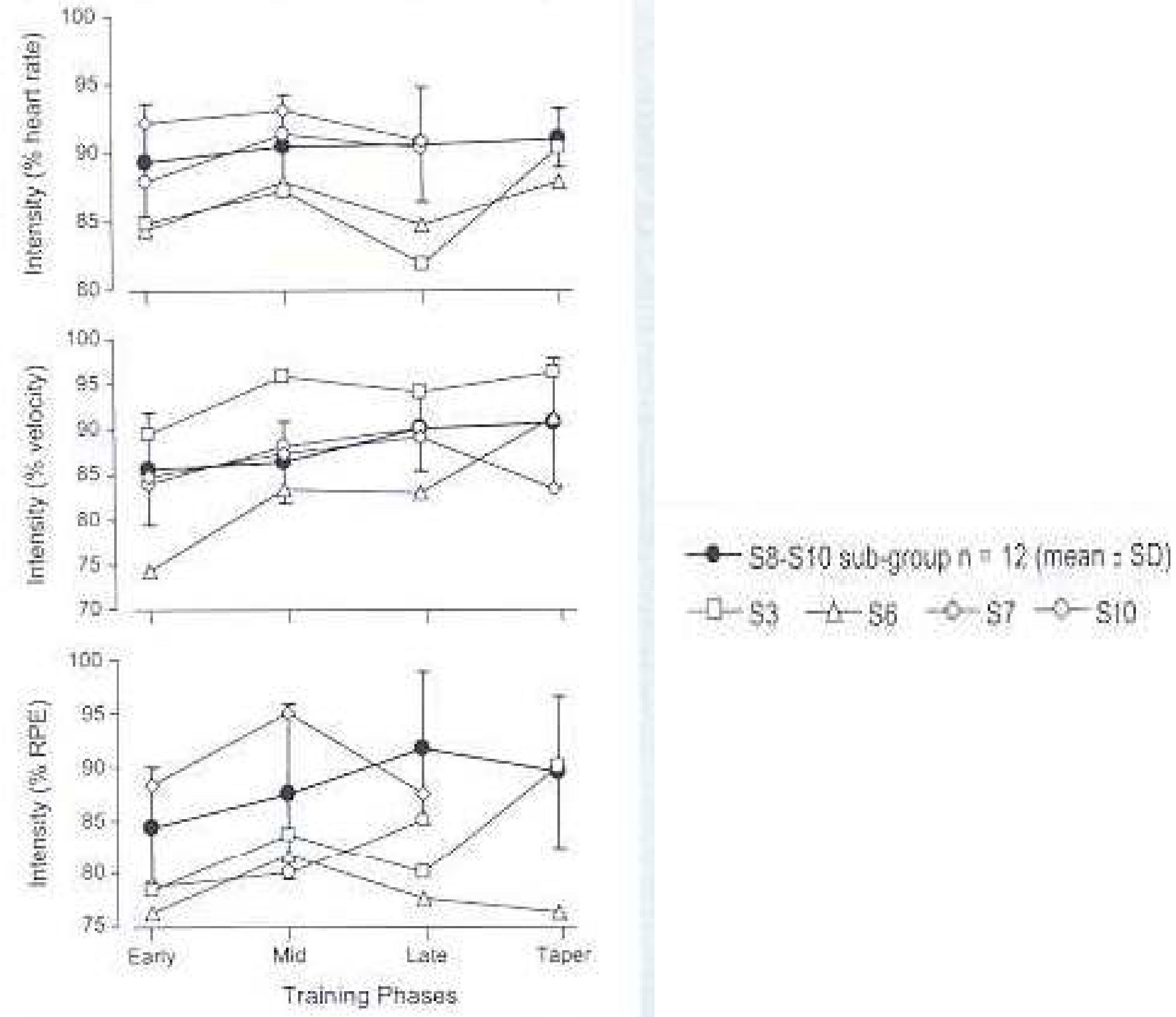
J Strength Cond Res



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Training Practices

- Effects of an 8-week resistance training program on static and dynamic strength and power performance examined
  - Performed twice per week with 5 sets of 10-12 repetitions of the bench press
  - 16 subjects (8 spinal cord injured and 8 able-bodied controls)

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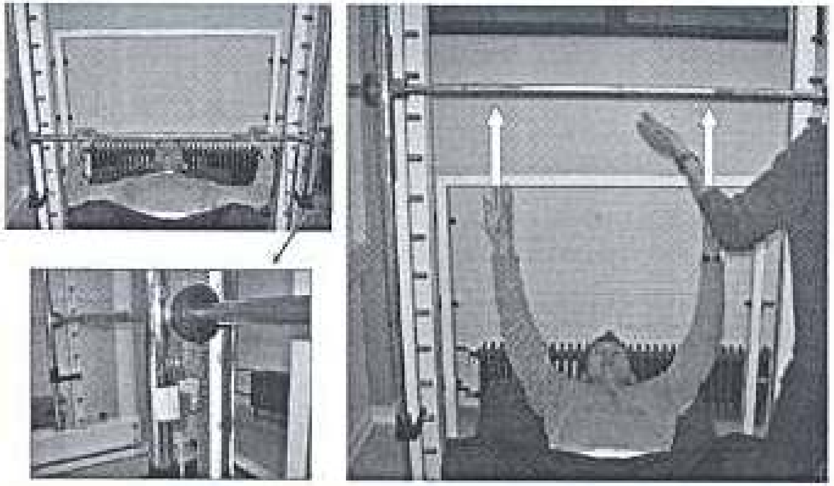

Figure 1. Measurement device for the registration of movement speed in upper extremities (analyzed parameters: v_{max}, a_{max}, t1, and t2) in a Smith machine.

Figure 2. Measurement device for the registration of maximal strength (F_{max}) and maximal rate of force development (MRFD) in upper extremities in isometric condition.

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Table 2. Absolute values for all parameters in pre- and post-testing (mean ± standard deviation).

	Wheelchair athletes		Control subjects	
	Pre	Post	Pre	Post
v_{max} (m/s)	2.39 ± 0.25	2.49 ± 0.24	2.82 ± 0.245	2.93 ± 0.203
a_{max} (m/s^2)	51.60 ± 14.12	63.00 ± 17.32	66.28 ± 11.24	69.38 ± 10.49
t_1 (ms)	14.40 ± 5.04	11.14 ± 3.65	11.89 ± 2.58	10.75 ± 1.36
t_2 (ms)	89.45 ± 16.67	78.45 ± 8.74	80.28 ± 8.47	77.14 ± 5.55
F_{max} (N)	732.50 ± 113.69	958.17 ± 124.46	895.88 ± 188.25	1,010.50 ± 100.56
MRFD (N/ms)	5.72 ± 0.52	9.73 ± 2.89	9.31 ± 1.65	9.94 ± 1.70
1 RM (kg)	77.90 ± 17.52	108.50 ± 28.59	89.31 ± 23.89	104.63 ± 25.59
Repetitions in SE	24.8 ± 7.8	41.3 ± 4.8	23.5 ± 2.9	36.8 ± 6.0
Sprint (seconds)	4.34 ± 0.37	4.26 ± 0.22	–	–

v_{max} = maximal velocity; a_{max} = maximal acceleration; t_1 and t_2 = time intervals representing the initial acceleration of the barbell; F_{max} = maximal strength; MRFD = maximal rate of force development; 1RM = 1 repetition maximum; *SE* = strength endurance.

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Applications of Research

- Still much to learn about:
  - The most important factors underlying performance in Paralympic sports
  - How Paralympic athletes respond to various training programs
  - Within- and between-athlete variability
- Limited sport performance studies suggest:
  - There are many similarities between Paralympic and Olympic athletes, but also many significant differences within- and between-groups
  - Coaches and sport scientists who work with Paralympic athletes need to be aware of these similarities and differences

Future Research Directions

- Continued research into sports-specific outcomes
  - Larger sample sizes so that more between-group analyses of Paralympic athletes can be done
    - May be best done at actual high-level events
  - Possible role of functional variability
  - Understanding progression and variability of performance is vital
  - Effect of training programs on performance

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