Biomechanics in Paralympic Swimming: Past, Present and Future

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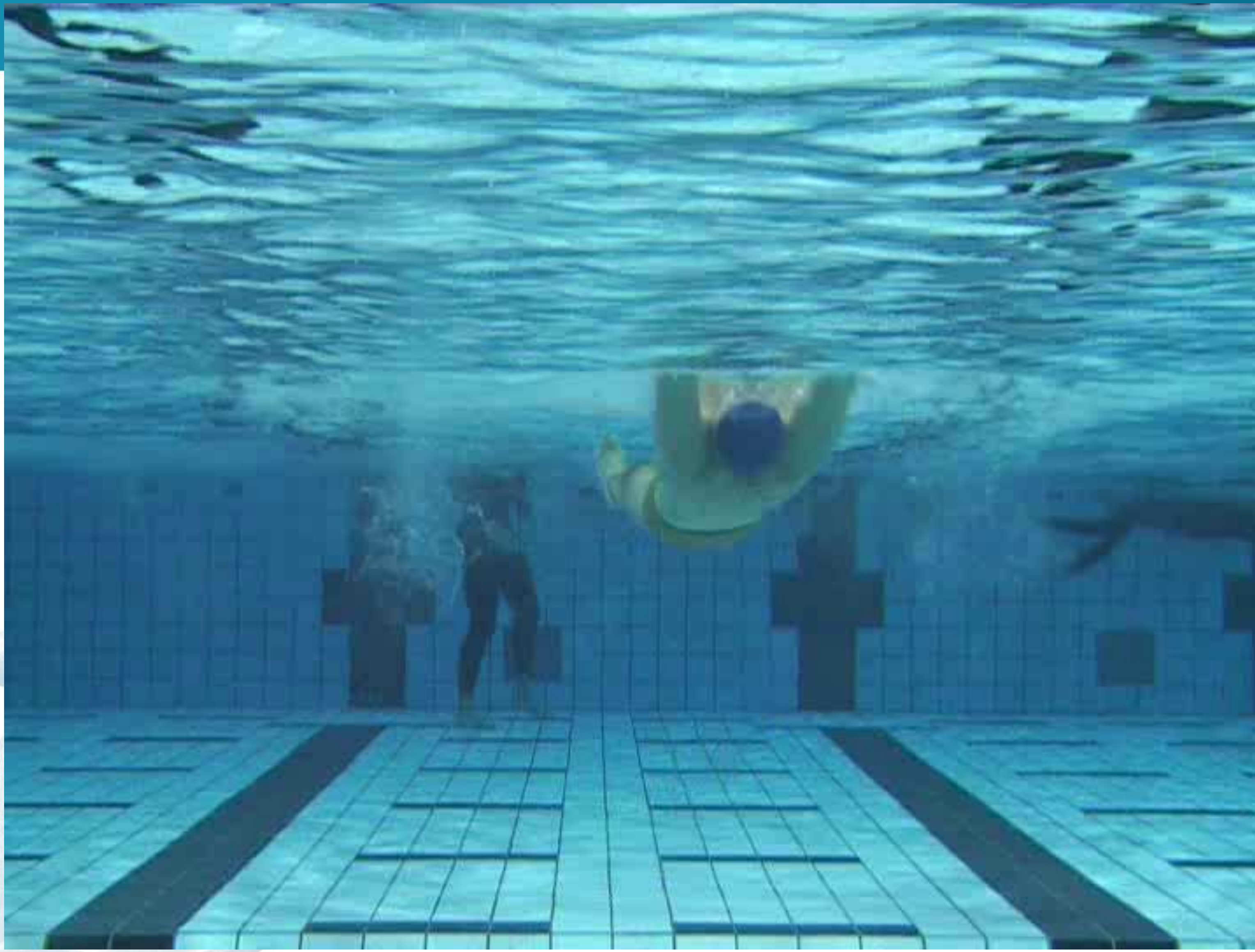
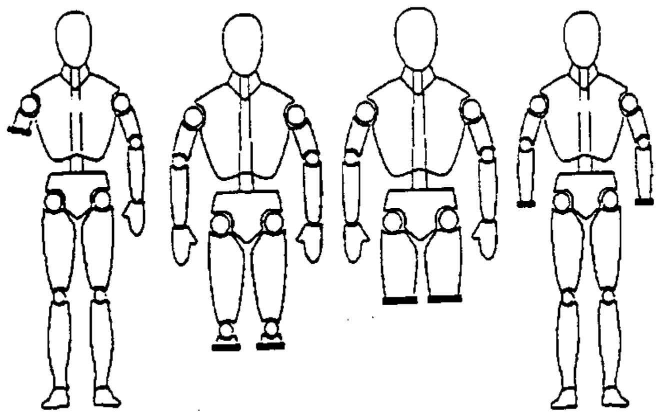


(Classification) Research

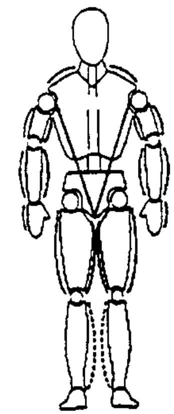
- Comparison of
  - End Race Result (Wu & Williams, Daly & Vanlandewijck, APAQ, 1999)
  - Race components (start, turn, finish) (Daly et al, APAQ, 2001; Malone et al. MSSE, 2001; Pelayo et al. MSSE, 1999)
  - Medals per impairment group (Wu & Williams, APAQ, 1999)
  - Swim Specific Physical Characteristics (Chatard et al. IJSM, 1990; Pelayo et al. EJAPOP, 1995)
  - Performance determining biomechanical factors

CLASS S8/10

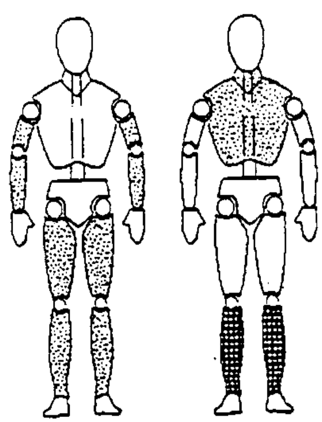
Amputees



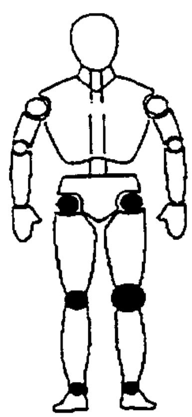
Para or Polio



Hemi or Diplegia



Joint restriction



Functional Classification Process

WATER

I. *Comparison with Profile in Manual*

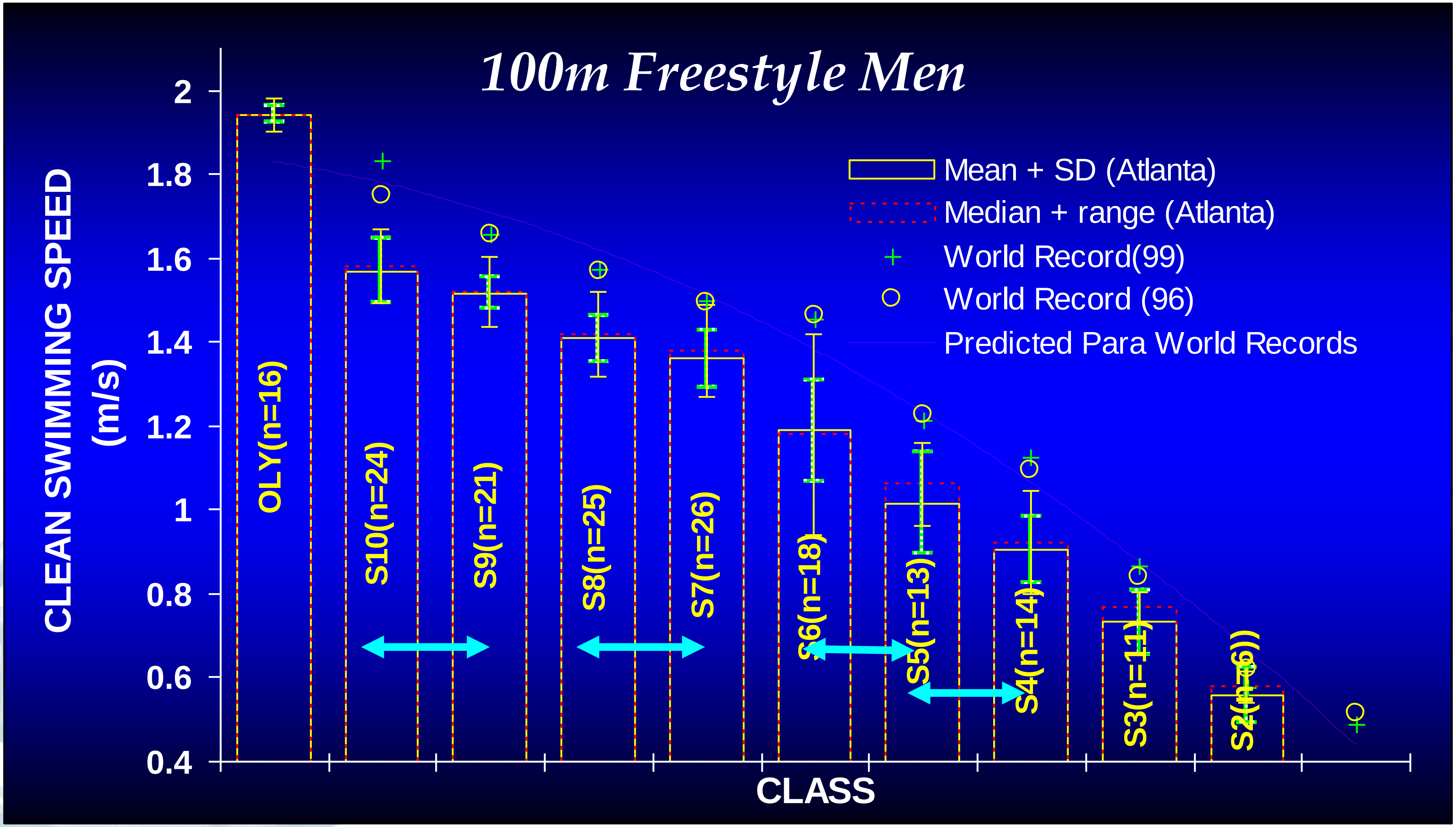
II. *Observation during competition*

Criteria for Classification Fairness (end race result)

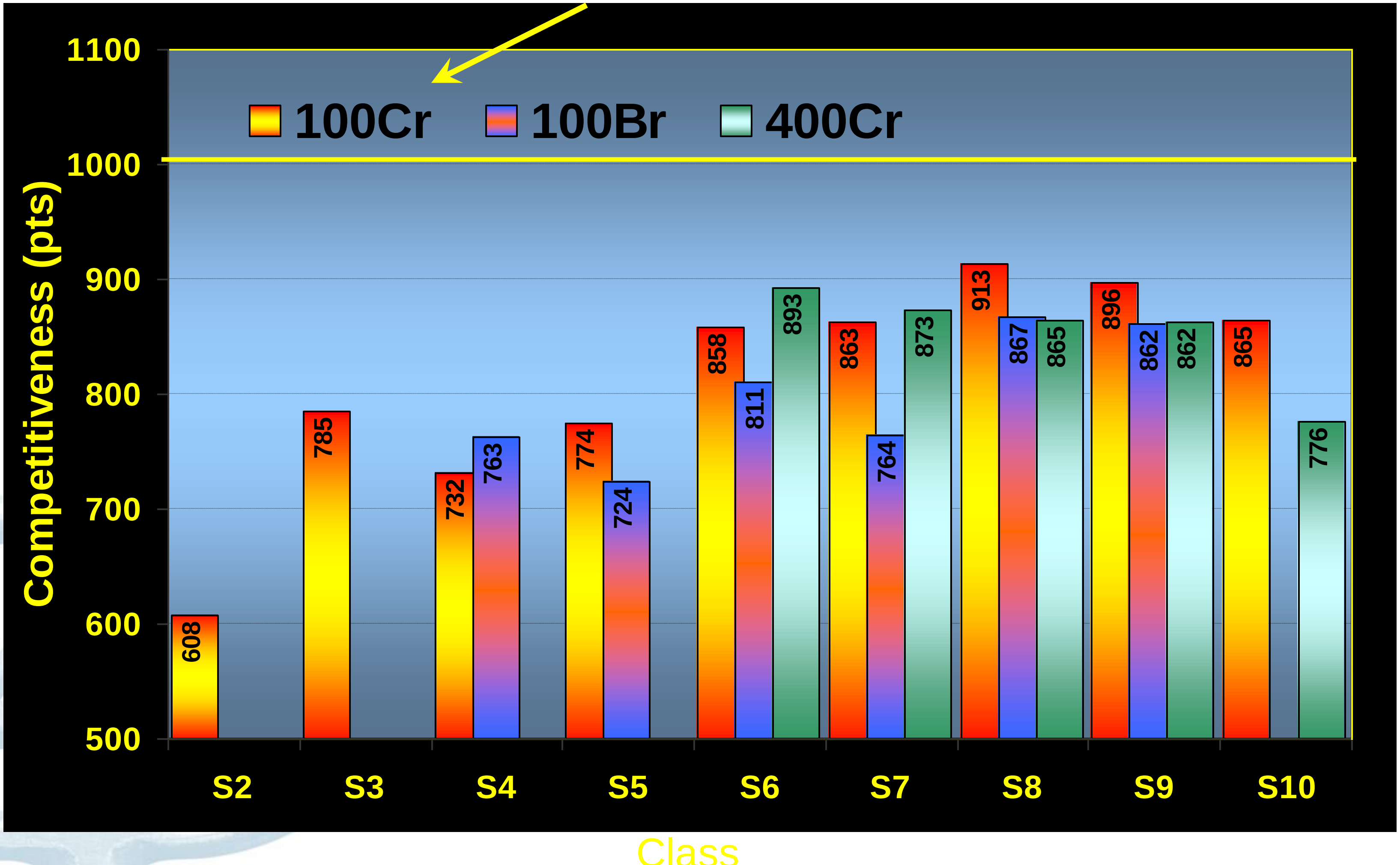
1. The speed of the world records should show a predictable decrease with decreasing functional class.

2. Race performances of the best swimmers should clearly discriminate among classes.

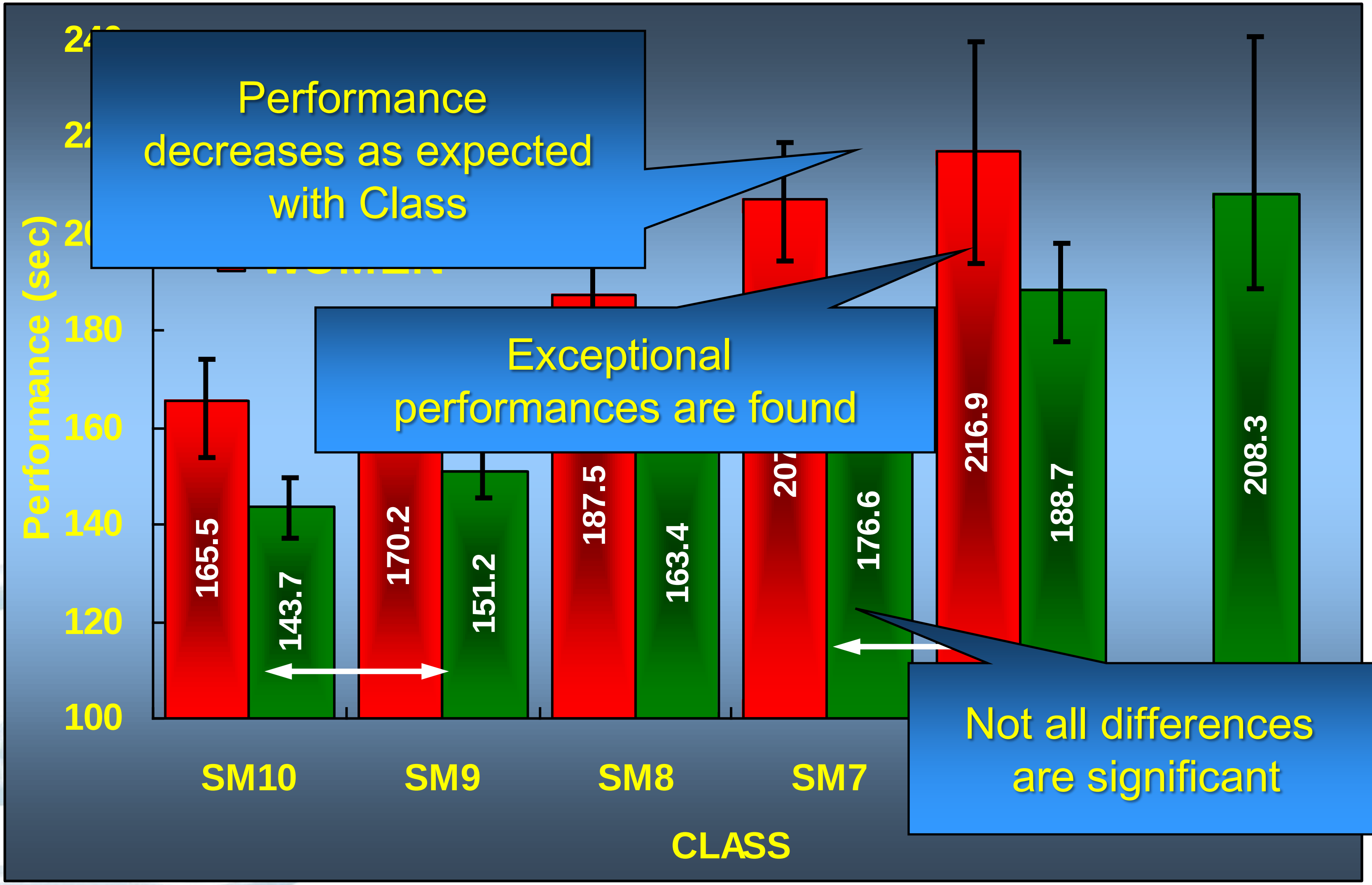
The speed of the world records should show a predictable decrease with decreasing functional class



Competitiveness in Male Finalists (1000pts = Class World Record)



Comparison of Race Results Among Classes: Medley



Race parts: 200-m Medley: End Results = start+swim+turn+finish

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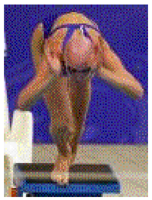
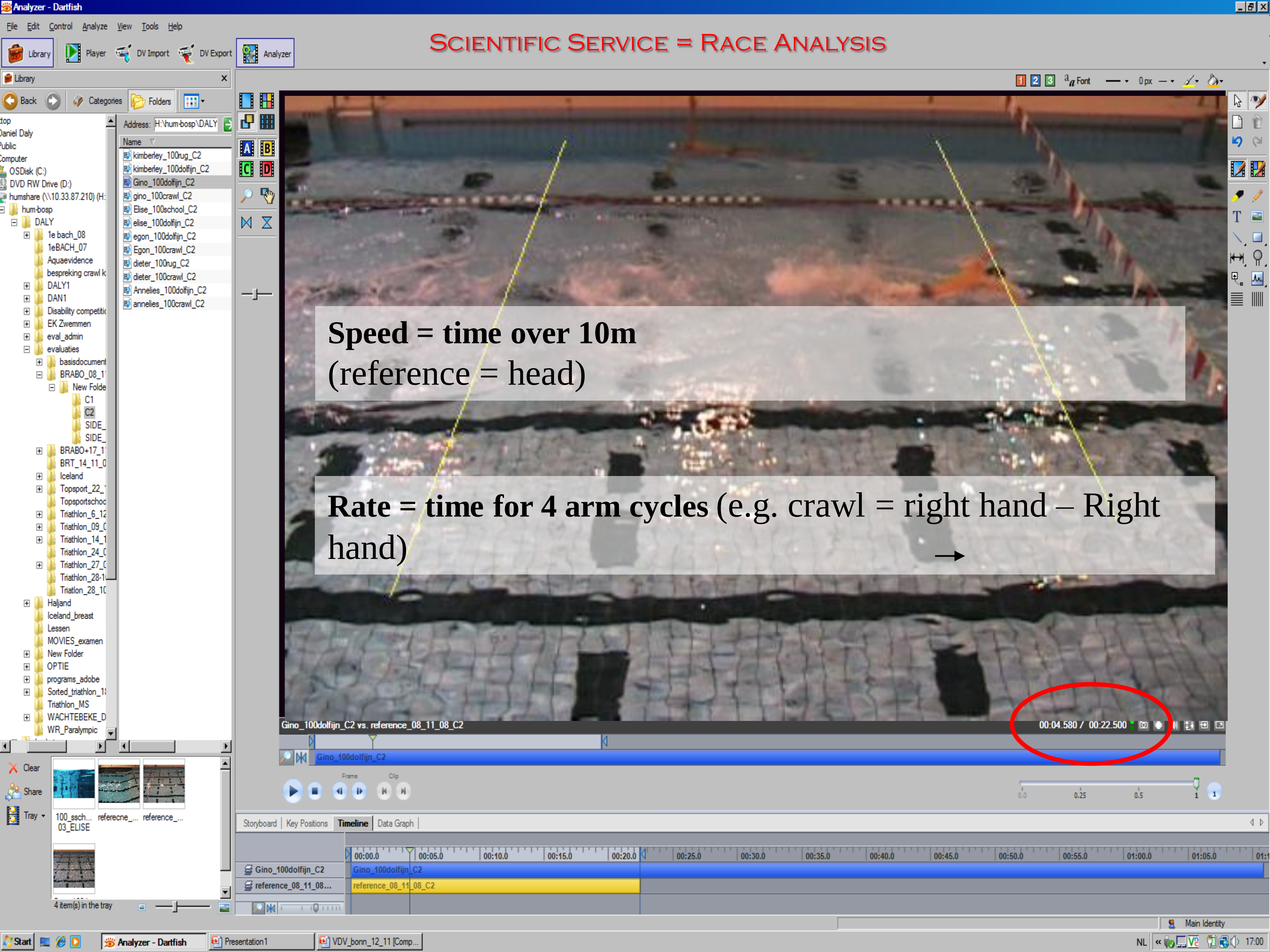


5m	15m	25m	45m
START (7.5%)	SEGMENT 1 BUTTERFLY (5%)	SEGMENT 2 BUTTERFLY (8.75%)	TURN IN (1) (3.75%)
RACE LAP 1 →			
TURN IN (2) (3.75%)	SEGMENT 4 BACKSTROKE (8.75%)	SEGMENT 3 BACKSTROKE (8.75%)	TURN OUT (1) (3.75%)
← RACE LAP 2			
TURN OUT (2) (3.75%)	SEGMENT 5 BREASTSTROKE (8.75%)	SEGMENT 6 BREASTSTROKE (8.75%)	TURN IN (3) (3.75%)
RACE LAP 3			
FINISH (2.5%)	SEGMENT 8 FREESTYLE (10.00%)	SEGMENT 7 FREESTYLE (8.75%)	TURN OUT (3) (3.75%)
← RACE LAP 4			

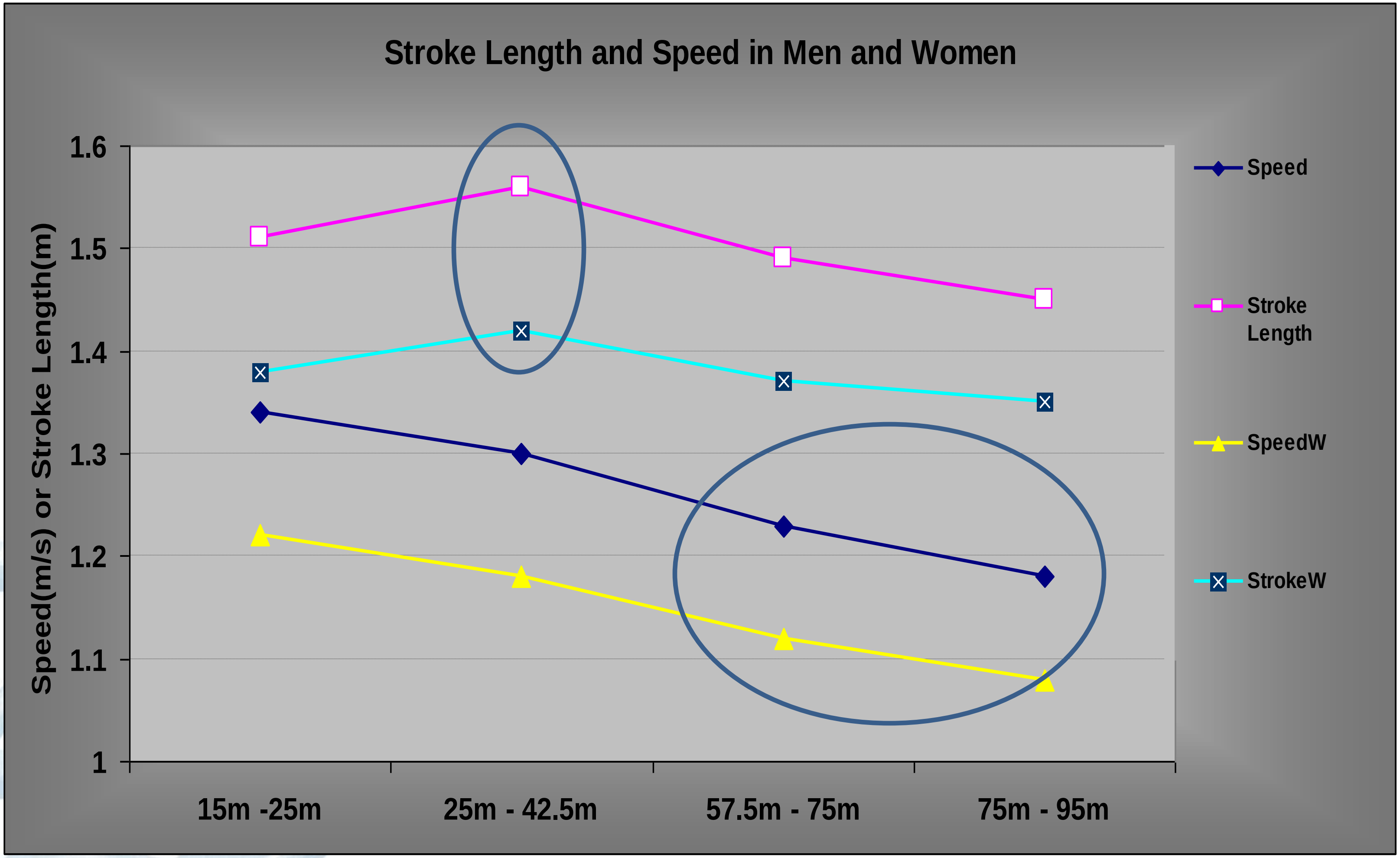
Scientific Service = Race Analysis



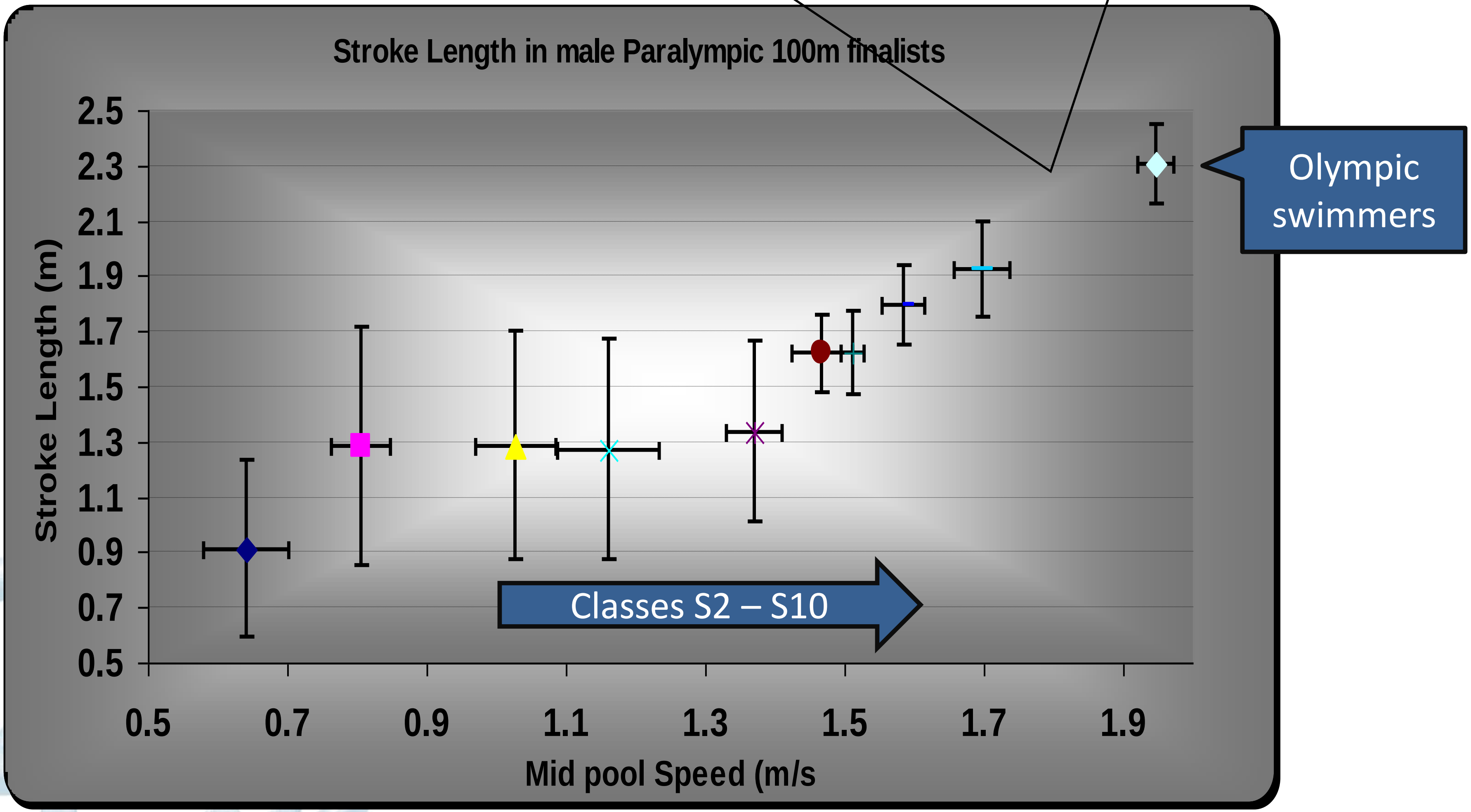
Speed = time over 10m
(reference = head)

Rate = time for 4 arm cycles (e.g. crawl = right hand – Right hand) →

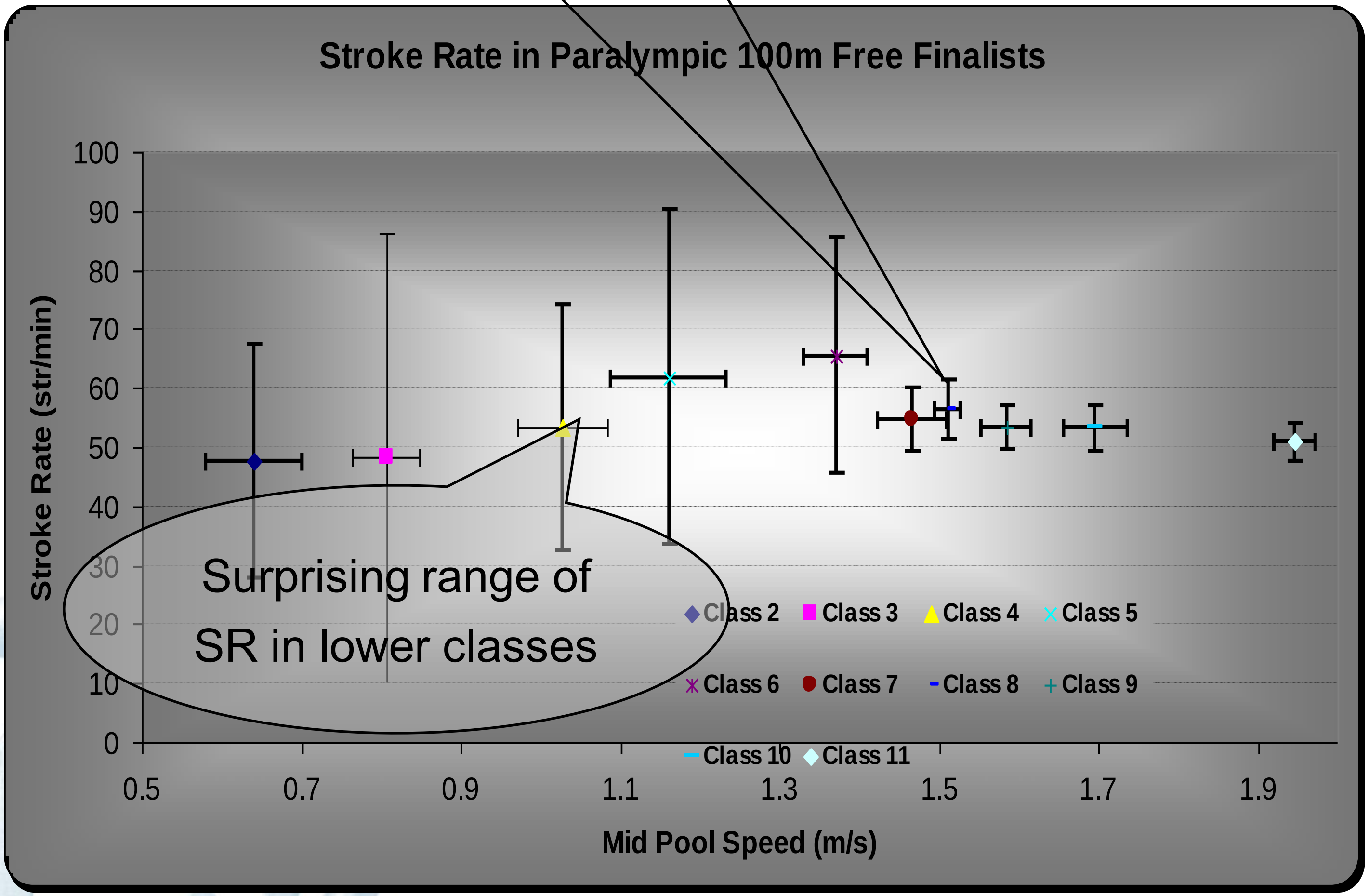
Race speed and stroking models are similar in all classes and between populations



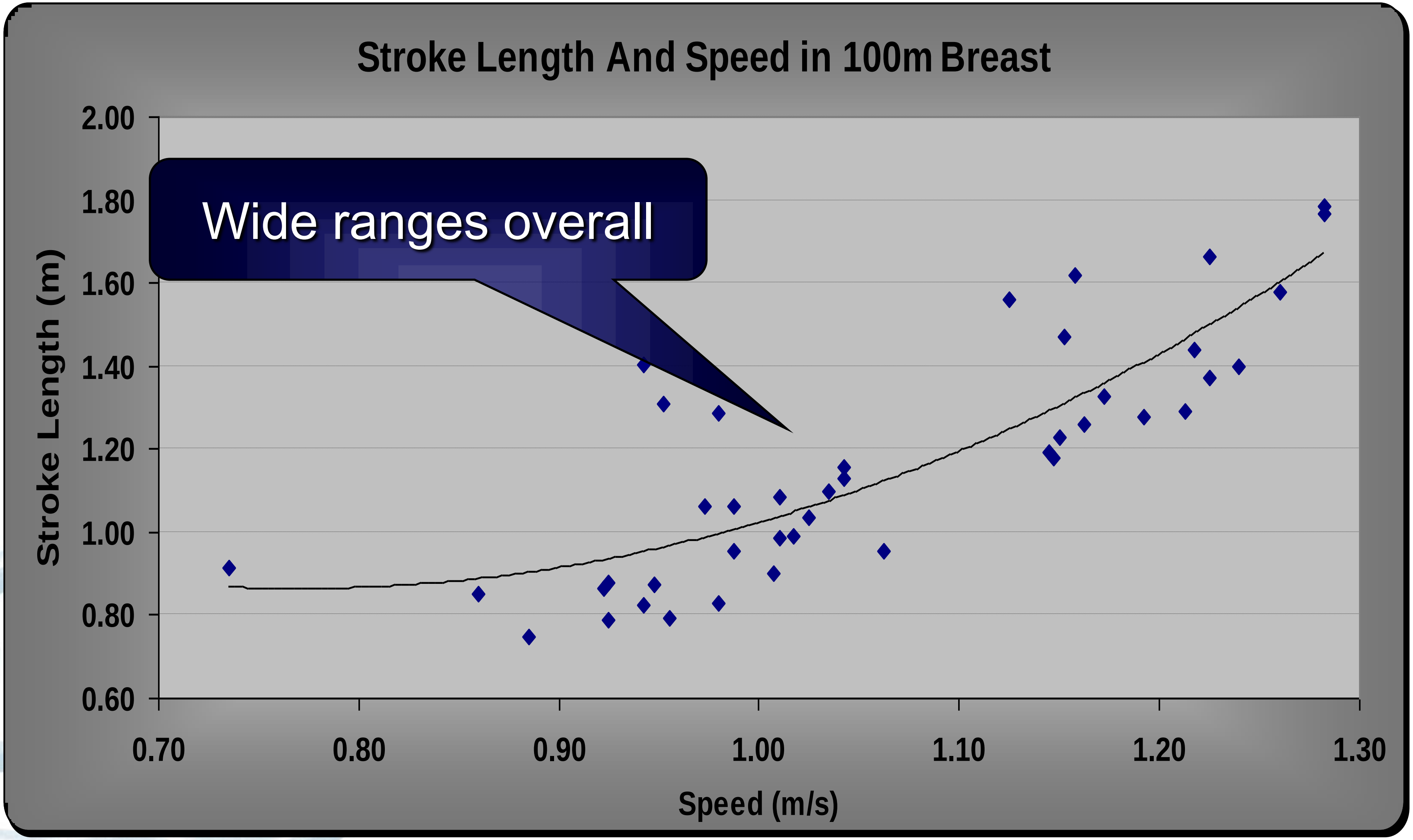
Relationship between Stroke Length and Speed is only clear in higher classes (Crawlstroke)



No relation Stroke Rate and Speed



BREASTSTROKE IS DIFFERENT?



Compare the specific functional abilities among classes

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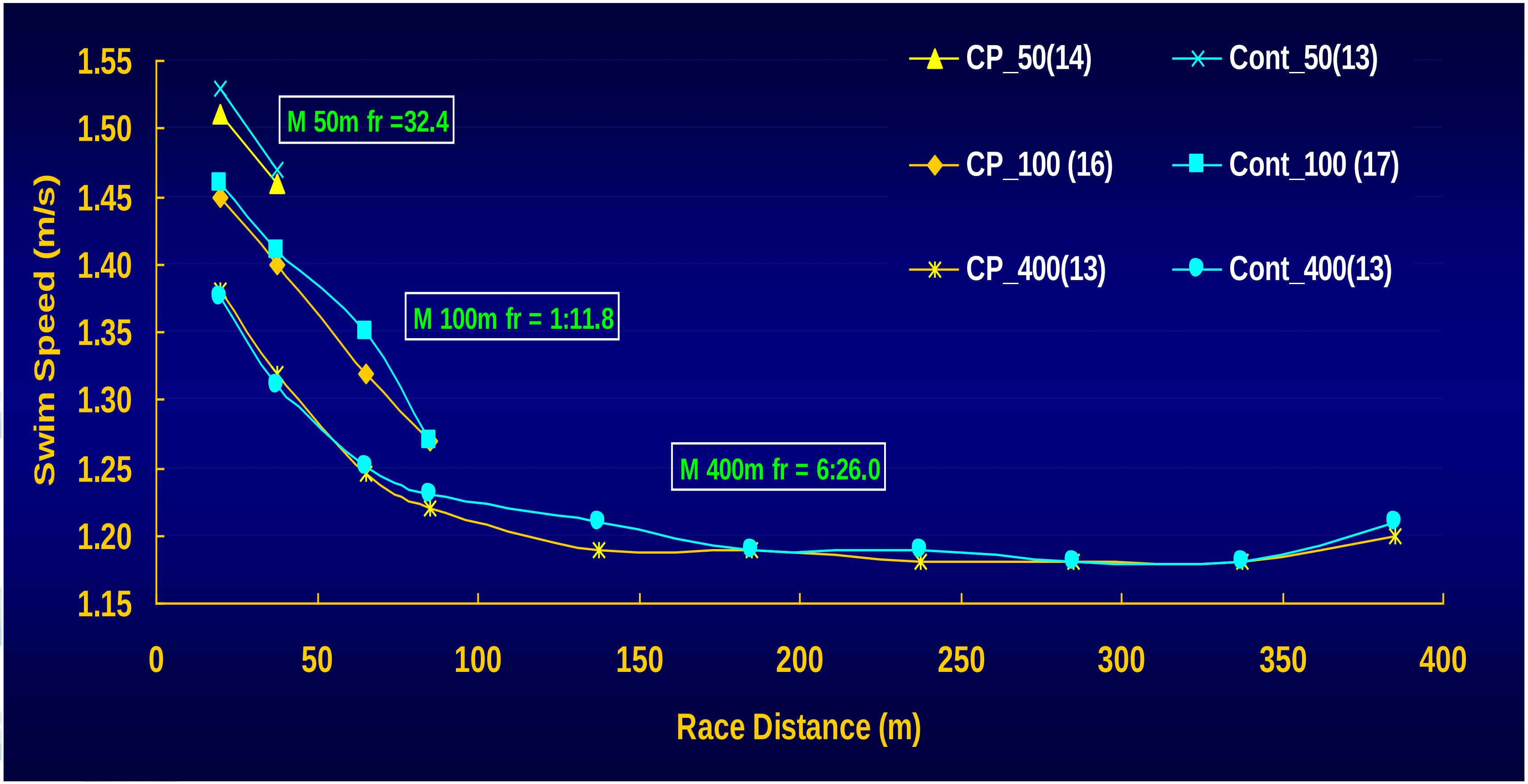
Swimming Speed in 50, 100 & 400-m Free in CP Swimmers and Controls



Stroke Length of CP Swimmers and Controls

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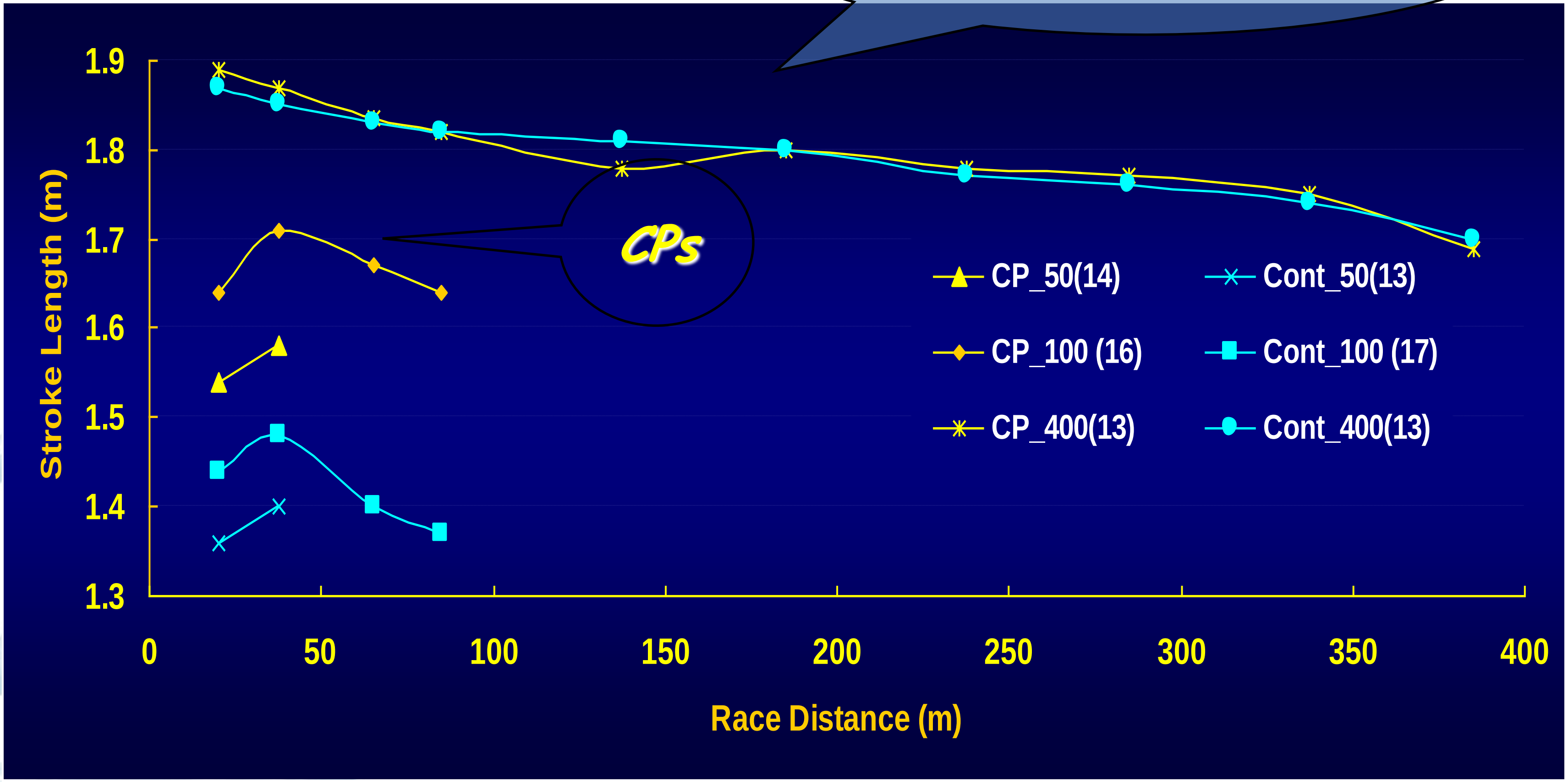
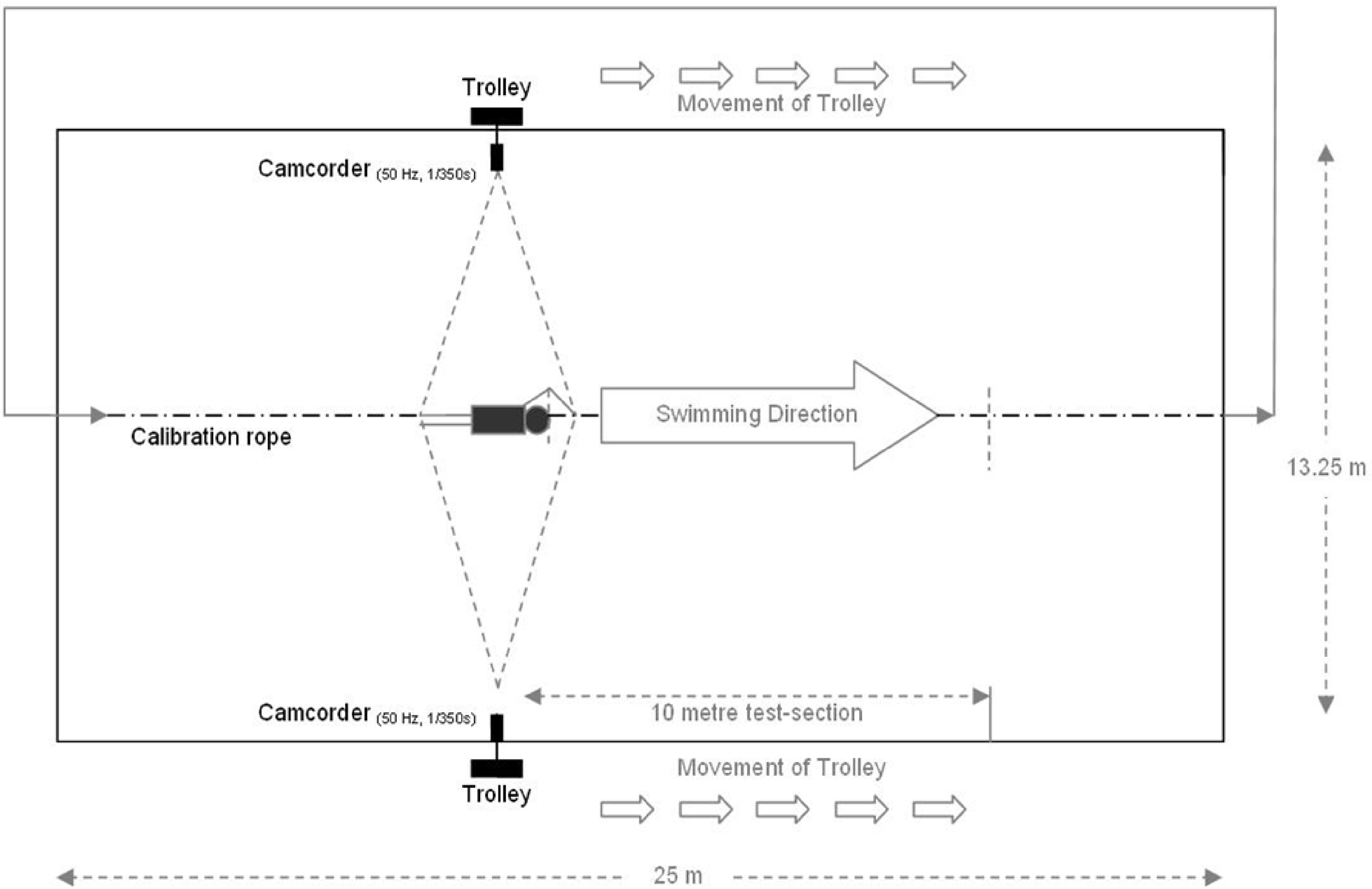
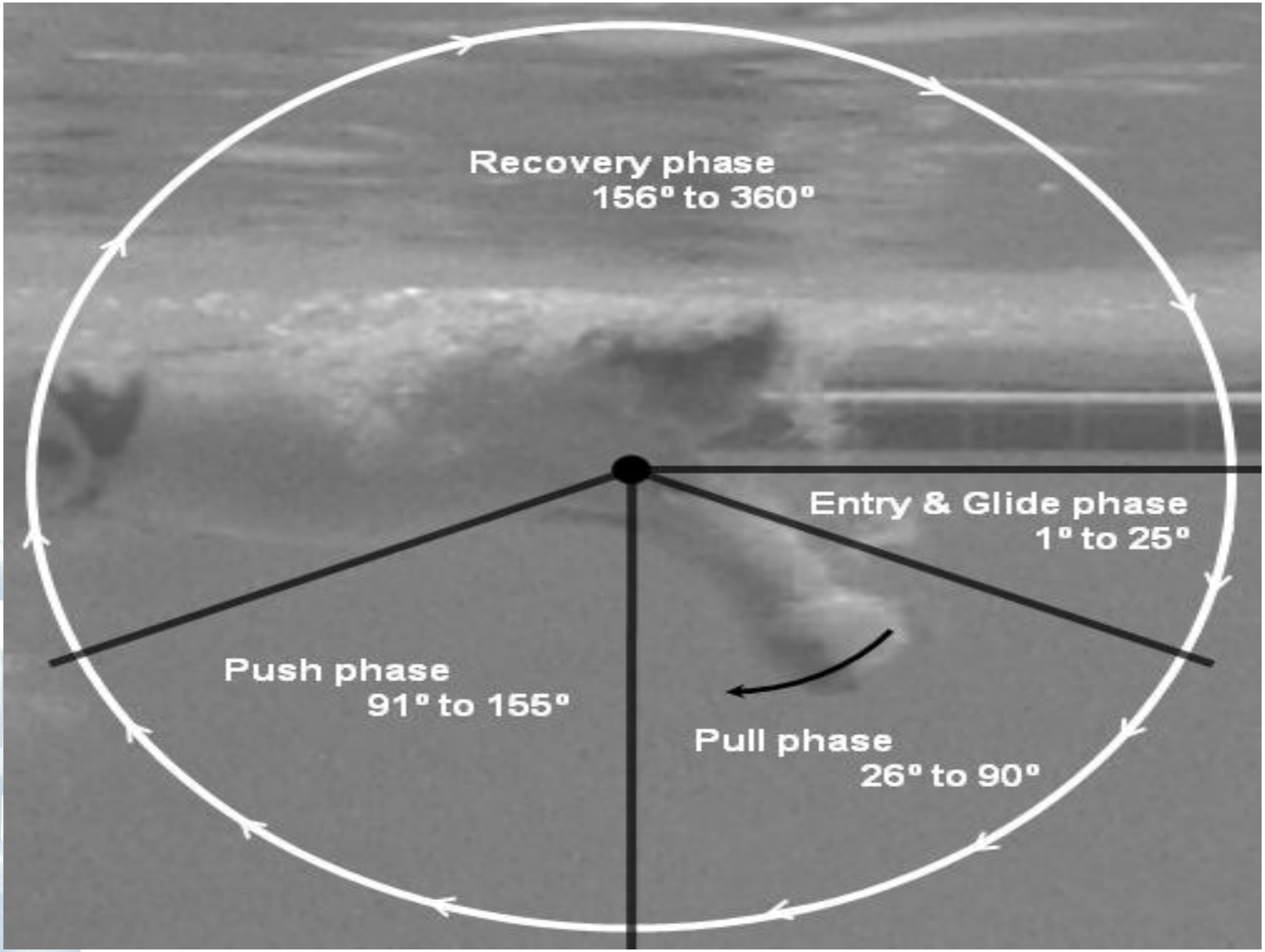
Different story than between race changes

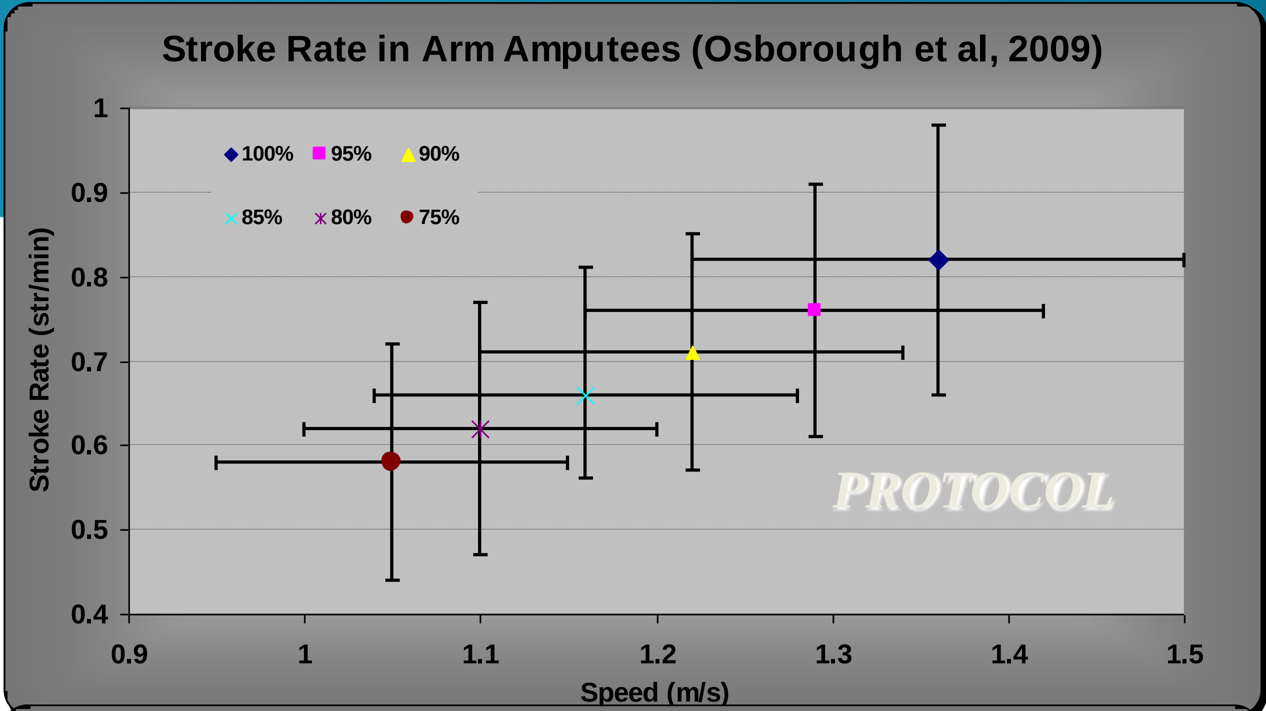


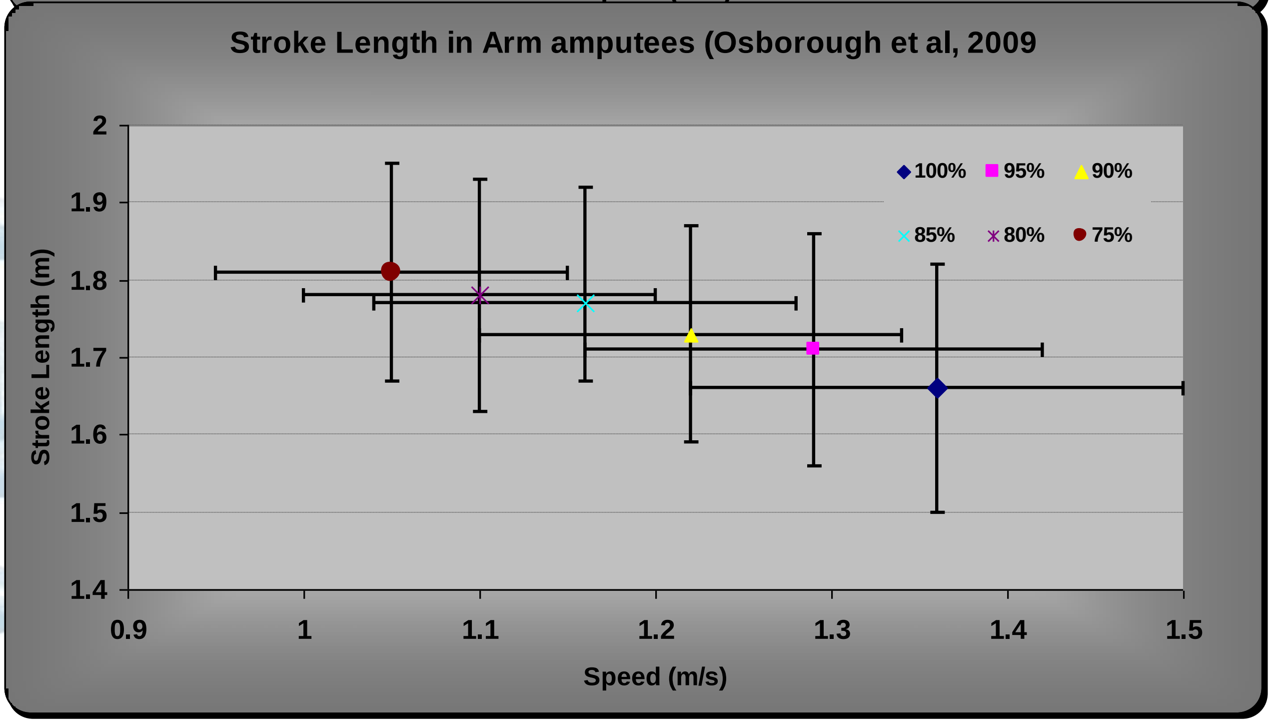
Osborough et al, 2009 & 2010



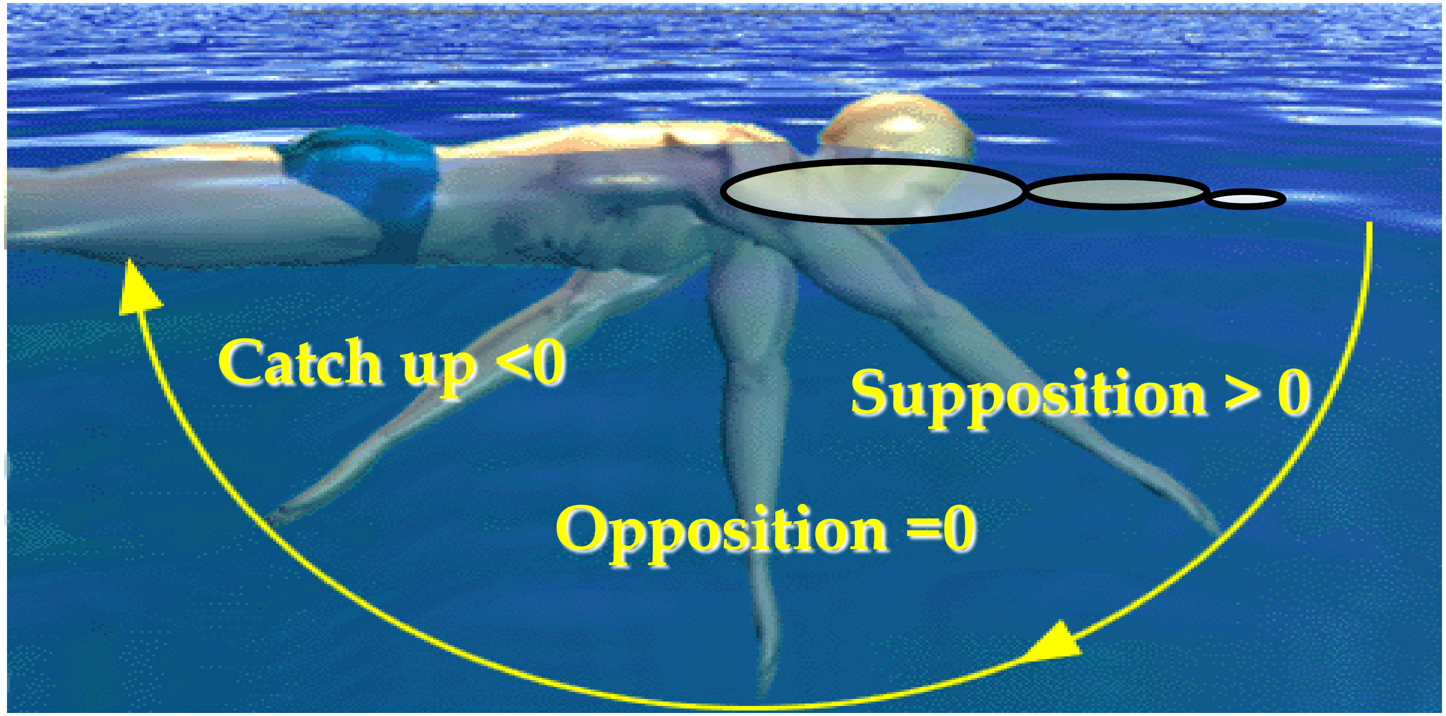
Arm co-ordination (Maglischo)



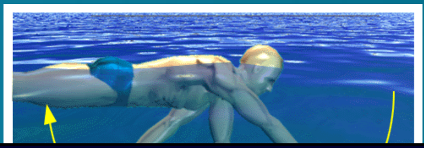

Stroke Rate in Arm Amputees (Osborough et al, 2009)
100%
95%
90%
85%
80%
75%
PROTOCOL
Stroke Rate (str/min)
Speed (m/s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.9
1
1.1
1.2
1.3
1.4
1.5


Stroke Length in Arm amputees (Osborough et al, 2009
100%
95%
90%
85%
80%
75%
Stroke Length (m)
Speed (m/s)
2
1.9
1.8
1.7
1.6
1.5
1.4
0.9
1
1.1
1.2
1.3
1.4
1.5

Arm co-ordination (Maglischo, Chollet, Seifert)



Arm co-ordination (100m race speed)



Group	Class	IdC (%)*	V (m/s)	Length (m)	Rate (st/min)	Points
I (4)	5.5	<-1.09	0.86	1.4	36.71	641
II (9)	7.67	0 - +8	1.1[illegible]	1.85	36.36	[illegible]
III (5)	6	+12 - +28	0.9[illegible]	1.42	[illegible]	[illegible]

No relation between IDC and SL or SR, Slight relation with relative performance

Disability swimmers use similar IDC to able bodied?

Satkunskiene et al (2005). Coordination in arm movements during crawl stroke in elite swimmers with a loco-motor disability. *Human movement science, 24*(1), 54-65.

Means and SD of adapted IDC (IdC_{adpt}), and IDC for both the affected (IdC_{aff}) and unaffected (IdC_{un}) arms for 13 crawl swimmers

	Percentage of maximum swimming speed (*M* *SD)*									
	80		85		90		95		100	
G.M [illegible] ***13)***										
IdC_{adpt} (%)	-16.5	4.5	-16.6	5.9	-17.3	5.6	-17.5	5.3	-17.3	5.2
IdC_{aff} (%)	-24.0	8.5	-24.1	8.[illegible]	[illegible]	8.5	-24.1	7.7	-24[illegible]	[illegible]
IdC_{un} (%)	-9.0	9.8 [a]	-9.1	10.4 [a]	-10.8	9.5 [a]	-10.8	8.8 [a]	-10.2	8.7 [a]

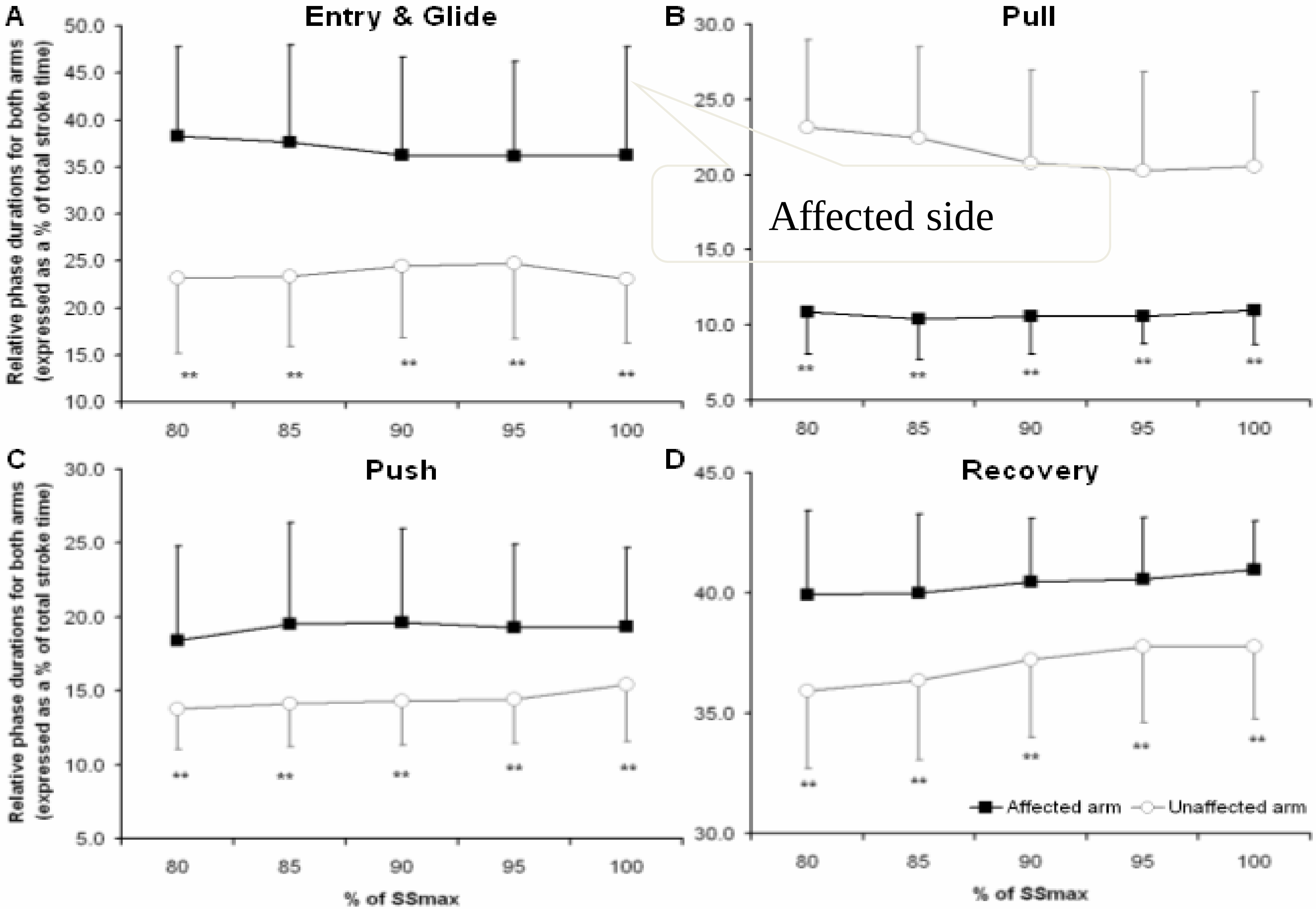
Affected side = considerably more Catch-up

No change with increased speed

Note 1: [a] Differences between IdC_{aff} and IdC_{un} are statistically significant (*$p < 0.01$)*.

Osborough at al (2009). Relationships between the front crawl stroke parameters of competitive unilateral arm amputee swimmers, with selected anthropometric characteristics. *Journal of applied biomechanics*.

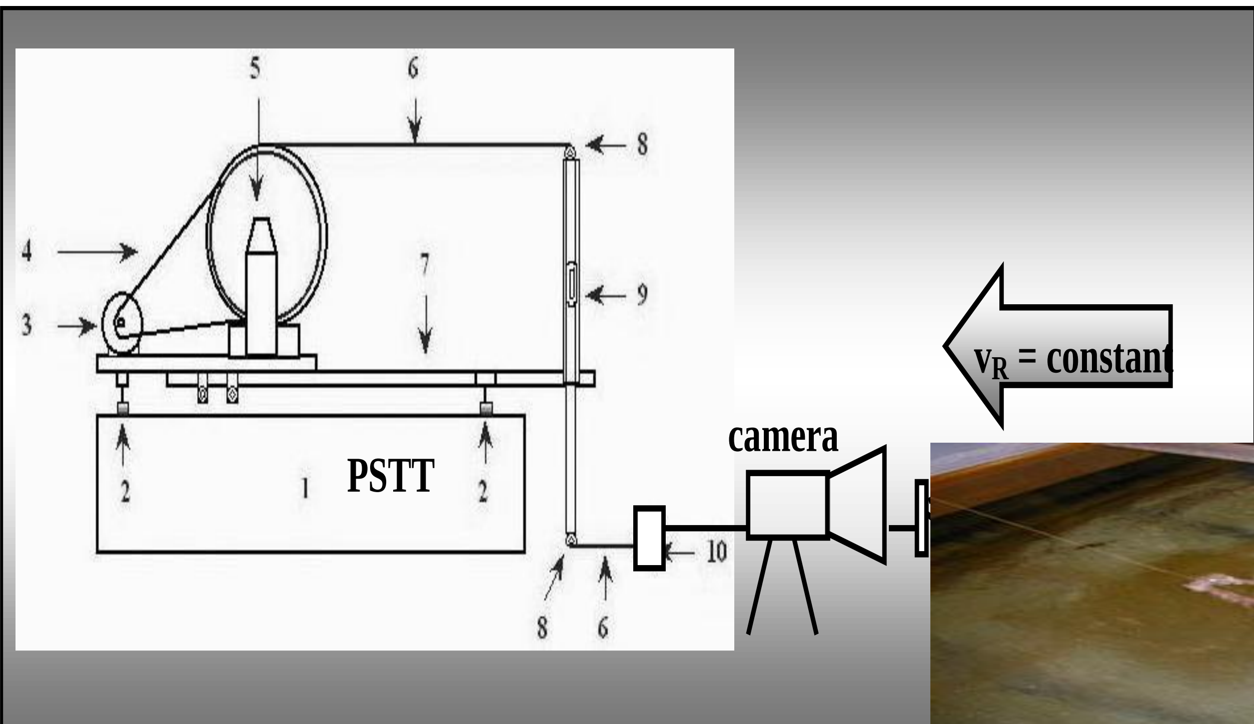
Relative arm stroke phase durations for both the affected and unaffected arms



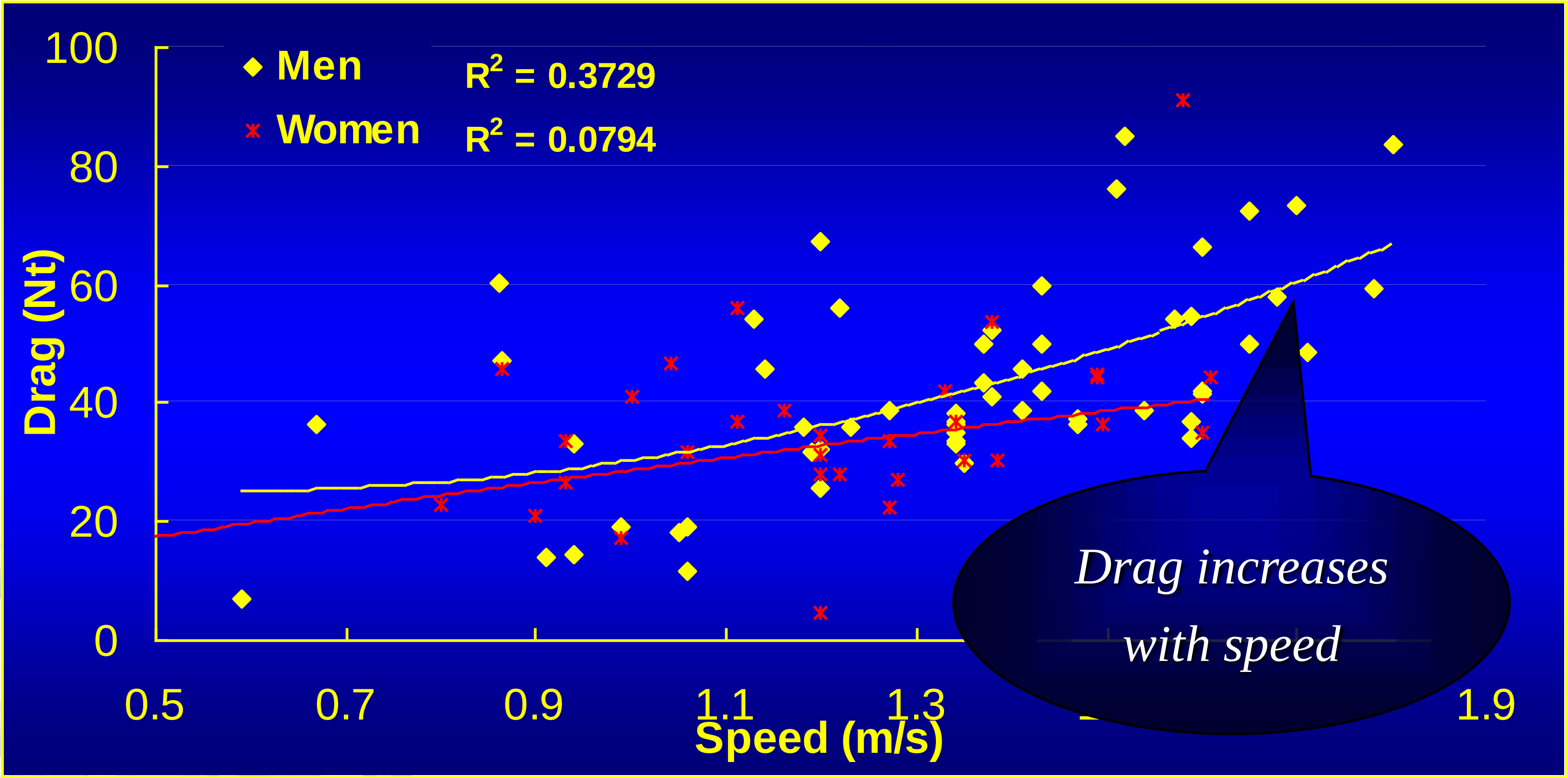
Take Home Message

As a consequence of being deprived of an important propelling limb, at fast swimming speeds SF is more important than SL in influencing the performance outcome of these single-arm amputee swimmers.

Passive drag testing



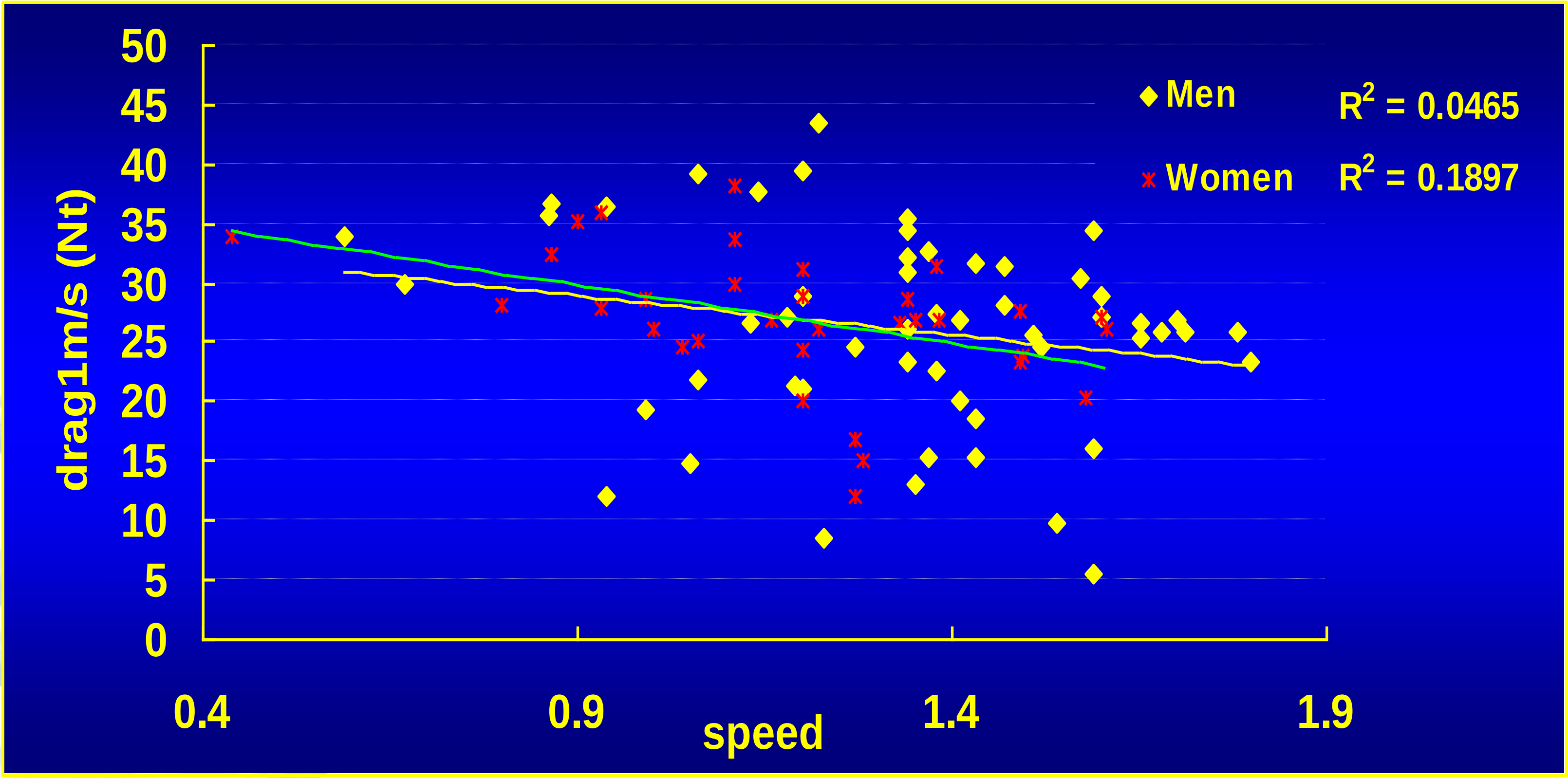
Passive drag at race speed



Passive drag(1m/s) vs race speed

•Drag decreases with class but the variablity is equal over speed.

•Propulsion more related to speed than drag but drag easier to decrease



Research Question

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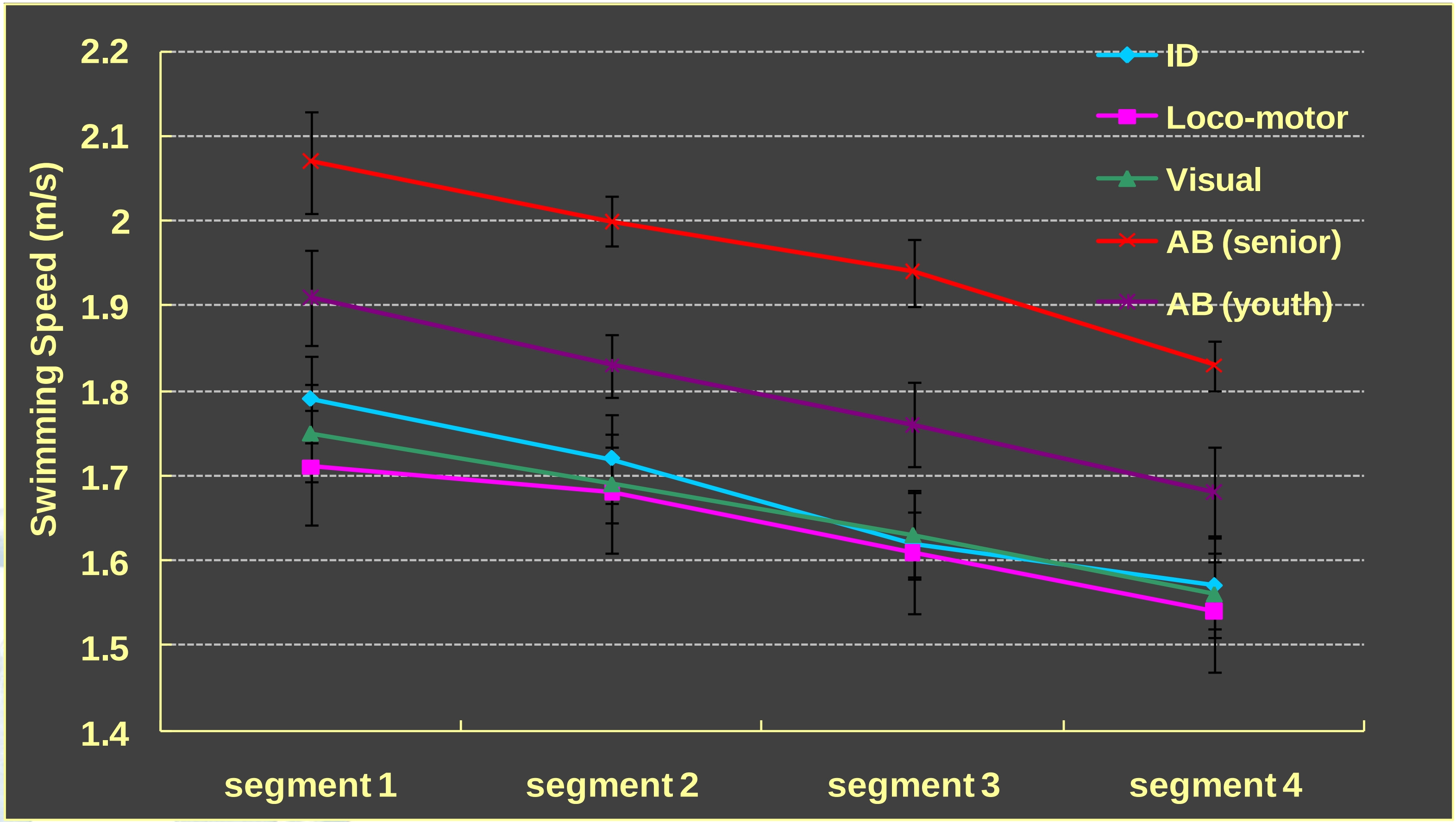
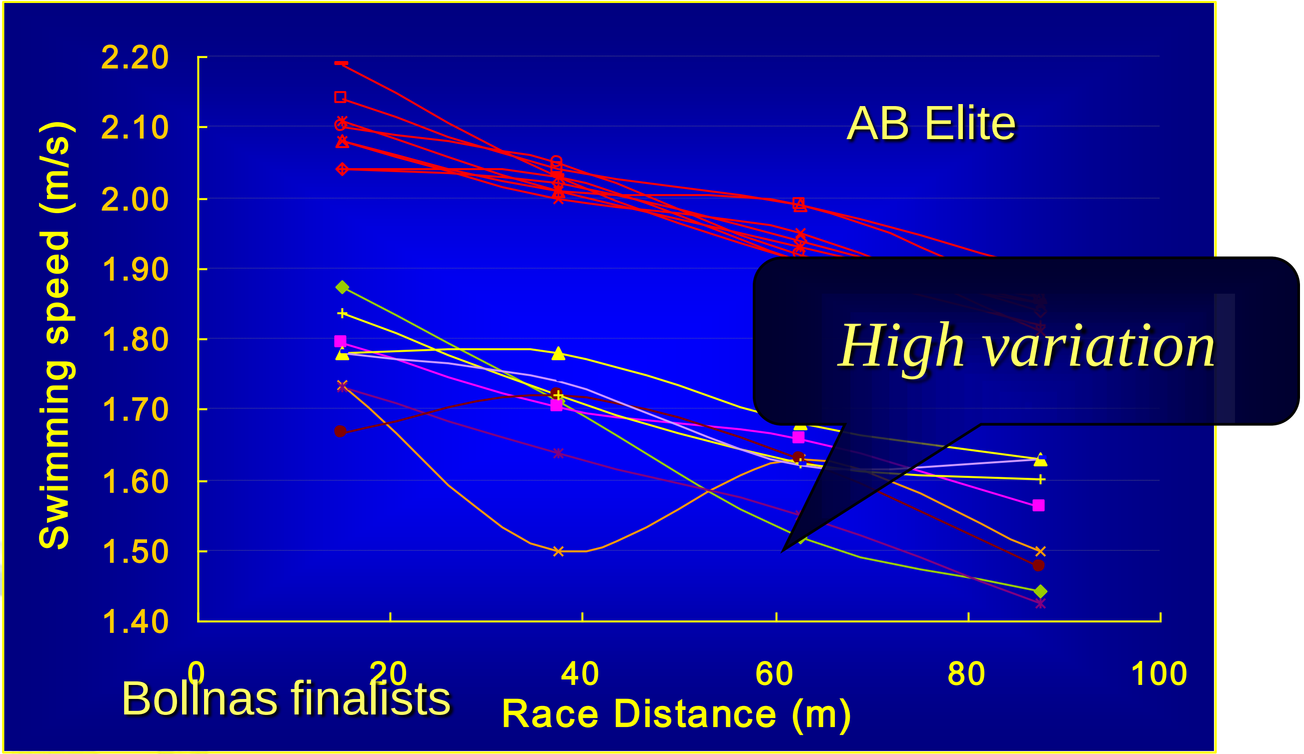
- 100-m free Paralympic competitors with a loco-motor disability all use similar speed and arm stroking race patterns (Daly et al. 2003).
- Do trained and experienced Intellectual Disability swimmers generally adapt these patterns?

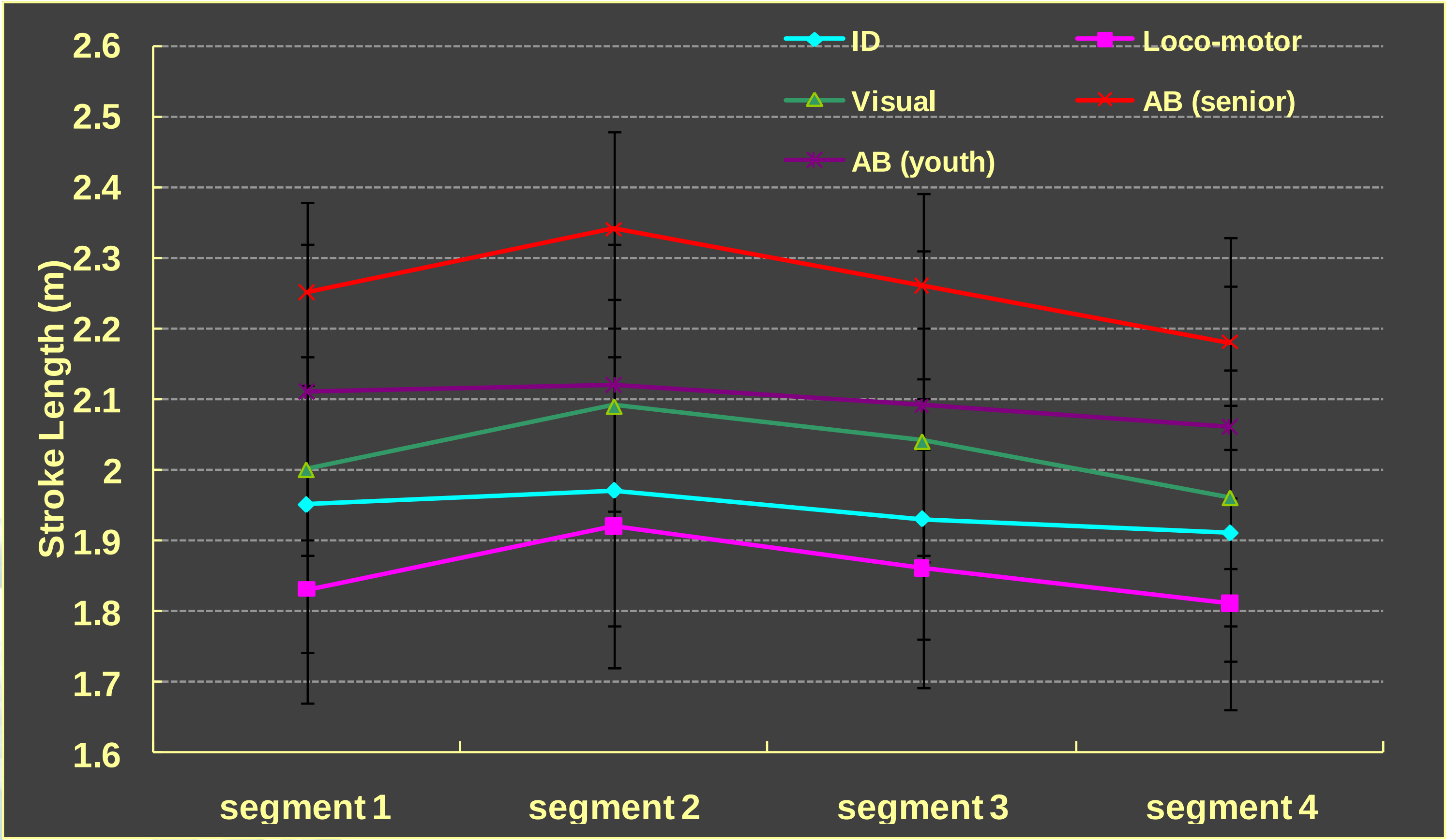
Mid-pool speeds for 5 groups of 100-m freestyle championship finalists



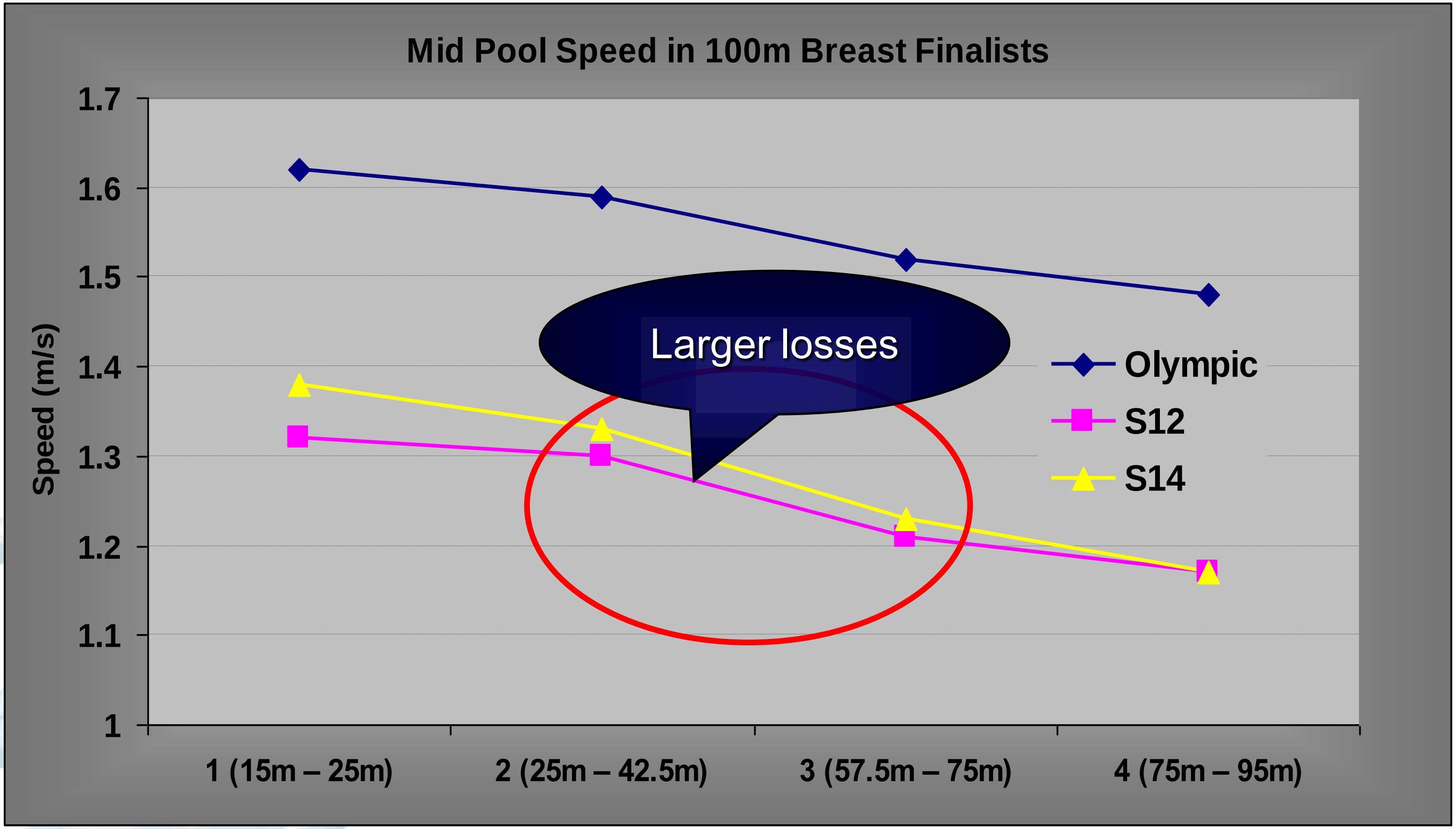
Experience: race speed pattern

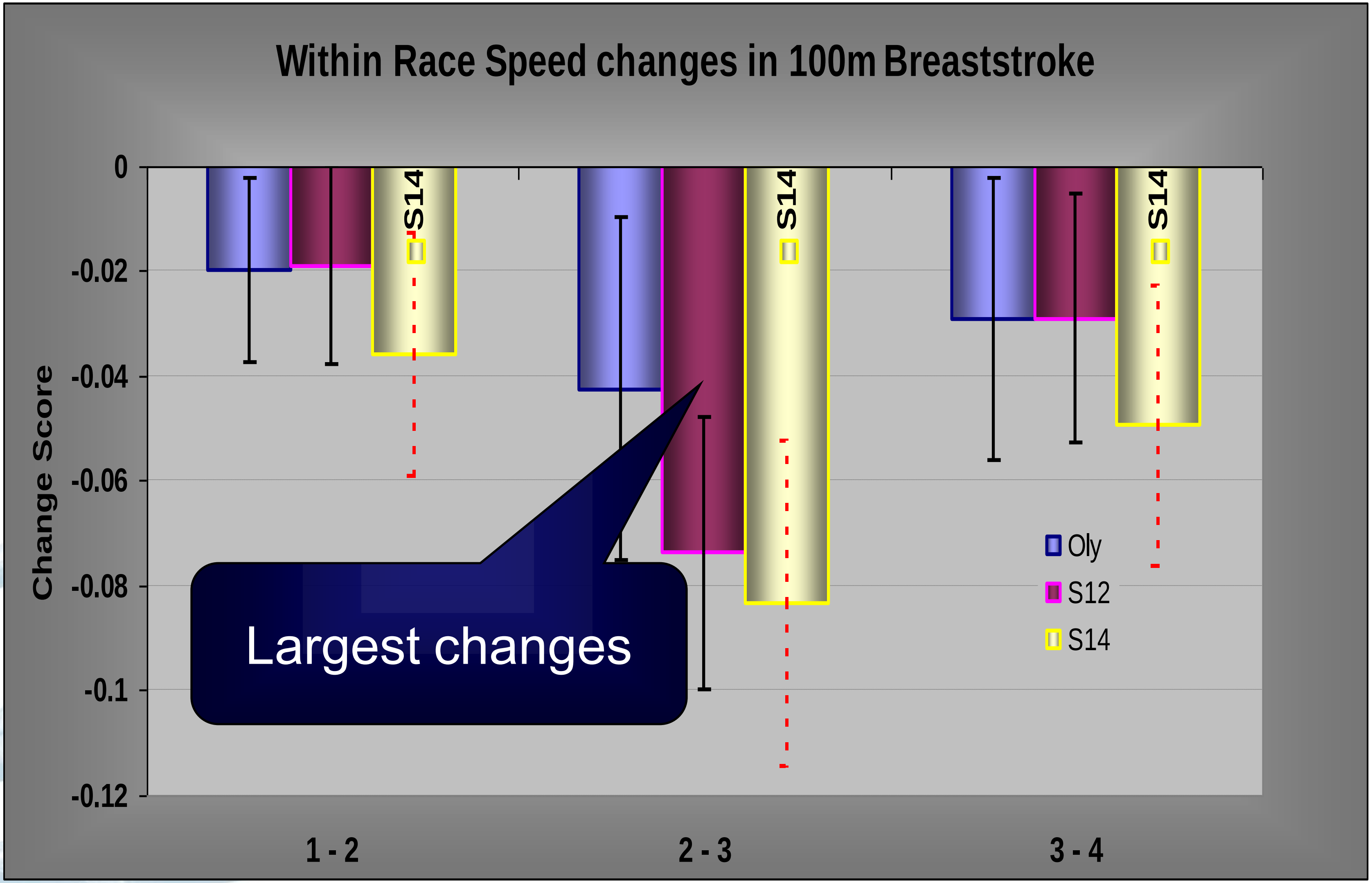


Stroke length per race segment for 5 groups of 100-m freestyle championship finalists



Race speed in 100-m Breast (50m)




Within Race Speed changes in 100m Breaststroke
Change Score
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
1 - 2
2 - 3
3 - 4
S14
S14
S14
Oly
S12
S14
Largest changes

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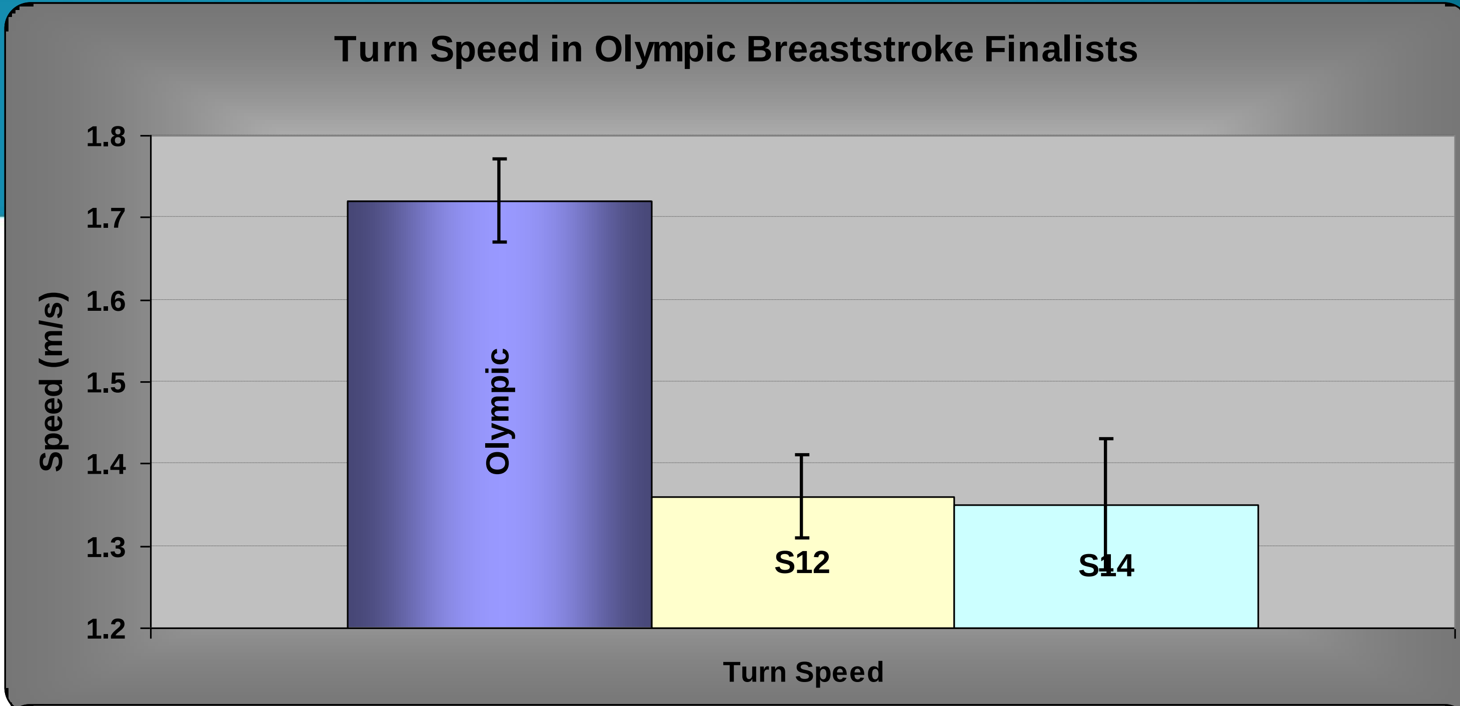
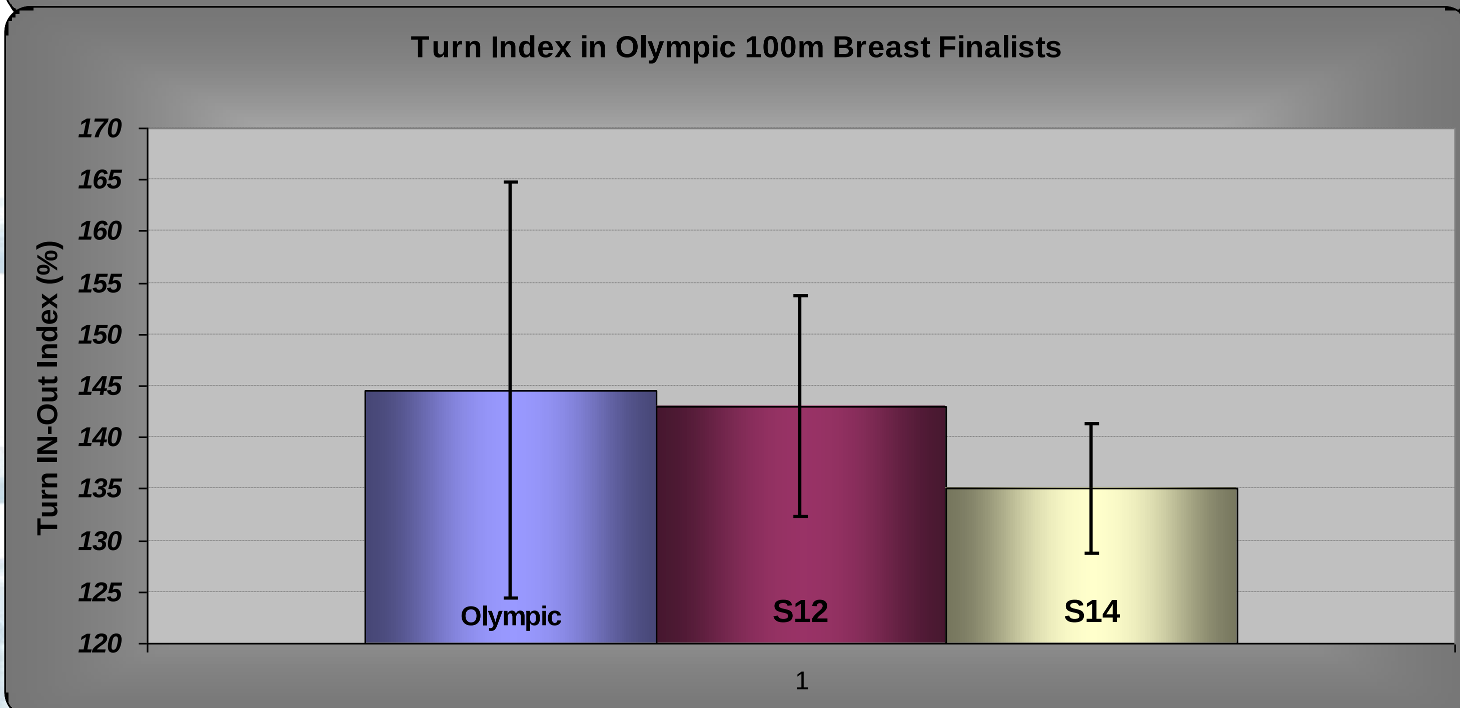




Relative Performance

Table 6: Mean performances for men and women finalists in Global Games swimming competition. 1=Actual times, 2=percentage scores related to the best American Age Group performances, 3= Point score related to ID event world record, 4= point score related to able bodied event world record.

Performances	MEN					WOMEN				
Time (finalists)[1]	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
50 crawl	5	25.84	0.91	24.59	26.92	6	31.79	3.20	29.40	38.09
100 crawl	6	57.78	2.19	55.17	61.18	6	68.26	3.54	64.86	74.44
50 back	6	31.43	1.47	30.09	33.56	6	36.11	2.80	32.37	39.70
100 back	6	66.38	1.41	63.74	67.82	6	83.39	6.27	75.06	91.00
50 breast	6	35.04	1.55	33.29	37.10	6	40.92	2.57	39.23	45.81
100 breast	5	76.01	3.02	71.52	78.78	6	88.49	3.30	85.32	93.97
50 fly	6	29.05	0.64	27.98	29.63	6	33.81	1.45	31.39	35.68
100 fly	6	68.47	1.77	66.37	71.03	5	79.88	3.98	73.36	83.90

1. ID swimmers are relatively poor in 100m fly (explosive strength)
2. ID women are less good than ID men.

Performances	n	Mean	SD	Min	Max	n	Mean	SD	Min	Max
100 back	6	887.31	39.20	830.16	1000.00	6	562.62	127.41	420.76	749.76
50 breast	6	629.92	81.34	525.57	727.47	6	706.14	114.83	494.68	787.68
100 breast	5	685.33	84.89	610.75	816.26	6	765.19	81.94	634.78	848.08
50 fly	6	895.45	61.33	842.07	1000.00	6	807.71	108.95	680.93	1000.00
100 fly	6	801.51	61.63	715.50	877.04	5	665.78	108.39	567.19	848.47
200 IM	6	844.63	132.65	645.06	991.42	6	707.95	133.48	520.22	838.73
AB point[4]										
50 crawl	5	547.99	58.54	481.53	631.79	6	425.95	99.83	237.55	516.59
100 crawl	6	516.44	57.49	432.02	589.15	6	440.09	63.46	335.01	506.45
50 back	6	410.33	55.10	333.37	462.51	6	423.17	102.75	308.67	569.42
100 back	6	437.20	29.16	408.95	492.61	6	323.62	73.29	242.02	431.27
50 breast	6	422.12	54.51	352.19	487.49	6	396.91	64.54	278.06	442.75
100 breast	5	435.63	53.96	388.22	518.85	6	395.10	42.31	327.76	437.90
50 fly	6	478.80	32.79	450.25	534.70	6	424.41	57.25	357.79	525.45
100 fly	6	369.34	28.40	329.70	404.14	5	355.44	57.87	302.81	452.97
200 IM	6	431.83	67.82	329.80	506.88	6	402.94	75.97	296.09	477.37

Body Structure Flexibility and Strength compared to European Elite

	Male	Finalists				Non	finalists						
Swim profile (percentile)	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	t-value	p	M&W
Height	9	32.333	38.036	4.00	97.00	22	14.409	17.970	0.00	60.00	1.35	.217	.029
Height/weight	9	28.778	33.018	0.00	100.00	22	27.227	31.580	0.00	100.00	0.12	.903	
Shoulder/hip	9	73.444	23.554	32.00	99.00	22	51.818	24.773	8.00	96.00	2.24	.033	.009
Endomorphy	8	21.500	24.296	0.00	72.00	22	26.545	27.148	0.00	84.00	-0.46	.648	
Vital capacity	7	48.571	25.251	13.00	76.00	19	38.737	34.241	0.00	100.00	0.69	.492	
Arm surface	9	30.667	36.163	0.00	97.00	22	7.864	10.508	0.00	33.00	1.86	.097	.087
Foot surface	9	33.444	27.281	1.00	83.00	22	30.909	22.663	1.00	74.00	0.27	.792	
Ankle flexion left	8	58.375	17.369	25.00	82.00	22	45.909	21.303	5.00	74.00	1.48	.150	
Ankle flexion right	8	58.375	17.369	25.00	82.00	22	45.909	21.303	5.00	74.00	1.48	.150	
Knee outward rotation	9	31.222	10.756	15.00	51.00	22	30.000	11.944	12.00	54.00	0.27	.792	
Hip outward rotation	9	41.333	4.950	33.00	48.00	22	35.045	13.974	15.00	66.00	1.85	.075	
Ankle supination	8	61.625	8.348	47.00	73.00	22	59.682	14.167	34.00	85.00	0.36	.719	
Hip inward rotation	9	34.556	13.929	17.00	59.00	22	28.500	9.941	15.00	49.00	1.37	.182	
Ankle extension left	8	49.875	8.079	37.00	62.00	22	49.318	5.489	41.00	65.00	0.22	.830	
Ankle extension right	8	49.875	8.079	[illegible]	62.00	22	49.318	[illegible]	41.00	65.00	0.22	.831	
Latissimus-pectoralis (L)	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
Latissimus-pectoralis (R)	9	22.556	28.649	0.00	77.00	19	24.895	25.166	0.00	98.00	-0.22	.828	
Triceps (L)	9	15.333	14.160	1.00	47.00	19	30.211	19.812	1.00	58.00	-2.01	.054	
Triceps (R)	9	16.333	17.132	1.00	52.00	19	28.368	20.125	1.00	56.00	-1.54	.135	
Pectoralis	9	20.444	26.097	2.00	80.00	18	34.611	36.819	0.00	99.00	-1.03	.320	
Handgrip (L)	8	14.750	30.969	0.00	91.00	21	22.476	28.128	0.00	100.00	-0.64	.525	
Handgrip (R)	8	14.375	31.131	0.00	91.00	21	23.429	29.065	0.00	100.00	-0.74	.468	
Eurofit Test battery													
Age (yrs)	7	21.143	2.410	17.00	25.00	19	22.053	3.922	17.00	29.00	-0.57	.573	.098
Height (cm)	9	180.211	10.715	171.30	199.40	22	172.427	8.573	158.30	186.50	2.14	.041	.045
Weight (kg)	9	77.489	10.657	60.00	90.40	22	69.018	13.331	55.30	118.70	1.69	.101	
BMI	7	23.763	3.940	18.78	30.08	21	23.440	3.336	18.82	34.70	0.21	.849	
Flamingo Balance (n)	7	1.286	0.488	1.00	2.00	21	1.524	1.470	1.00	7.00	-0.64	.526	
Plate tapping (0.s)	7	134.571	46.829	89.00	229.00	21	130.510	64.998	10.70	306.00	0.15	.880	
Sit and reach (cm)	7	34.000	15.780	4.00	50.00	21	35.690	7.417	20.00	46.00	-0.39	.701	
Standing broad jump (cm)	7	197.286	26.266	158.00	235.00	21	181.857	39.530	103.00	225.00	0.96	.347	
Sit ups (n in 30s)	7	23.000	6.782	12.00	31.00	21	20.714	4.724	13.00	28.00	0.99	.330	
Hand grip (kg)	7	38.429	12.908	26.00	62.00	21	38.000	10.588	13.00	58.00	0.09	.931	
Vertical jump (cm)	7	43.429	2.149	40.00	46.00	21	44.286	8.433	23.00	56.00	-0.43	.674	
Bent arm hang (0.s)	6	359.833	212.980	202.00	642.00	20	324.450	234.217	0.00	764.00	0.33	.744	
Shuttle run (s)	7	193.857	9.263	184.00	213.00	21	207.238	33.484	117.00	267.00	-1.65	.111	
Reaction speed (n line)	7	9.857	1.574	8.00	13.00	19	10.000	3.651	3.00	16.00	-0.14	.891	

ID swimmers have poor static strength

Turning problems in ID swimmers

Computational Fluid Dynamics (CFD) analysis

Computer simulation model of the swimmer developed.

Driven by real kinematic data from 3D video analysis.

Model is personalized to the swimmer by scanning in body segments.

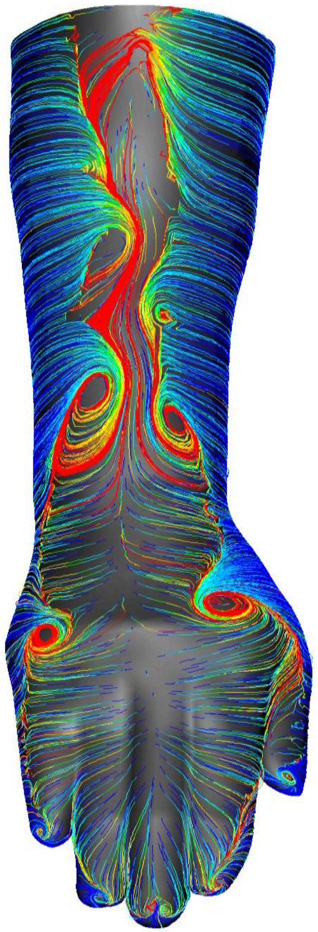
Propulsive and drag forces are calculated based on model input.

In near future, may help find the optimal solution for each swimmer.

* LIMITED to one hand movement

* Large financial investment

* Critical Mass may not be present



J Biomech. 2008 Sep 18;41(13):2855-9.
Using reverse engineering and computational fluid dynamics to investigate a lower arm amputee swimmer's performance. Lecrivain G, Slaouti A, Payton C, Kennedy I.

Optimizing kick rate and amplitude for Paralympic swimmers via net force measures FULTON et al. 2011 JSS

- Determine optimum kick characteristics, 12 Paralympic swimmers aged 19.8+2.9 years (mean … idual peak freestyle speed.
- Conditions (i) a prone … trials and (ii) maximal freestyle kicking in a p… als at different speeds and kick amplitudes. K… g inertial sensor technology.
- Speed was assessed … dynamometer, and net force was assessed u… system.
- When peak speed wa… e force increased 24.2+5.3% (90% conf… remained at *150 kicks per minute.
- Larger amplitude kicki… orce by 25.1+10.6%, although kick rate decreased substantially by 13.6+5.1%.
- The kick rate and amplitude profile adopted by Paralympic swimmers are appropriate

Figure 1. Inertial sensor package (MiniTraqua™) used to quantify kick count and kick rate. The image is presented to scale and is orientated as it appeared on the thigh and shank during testing.

The Influence of Swimming Start Components for Selected Olympic and Paralympic Swimmers, Burkett et al. 2010 , *J. Applied Biom.*

Olympic and Disability	Olympic (n = 5)	Arm Amp (n = 4)	Leg Amp (n = 4)	CP (n = 7)
Time (s)				
Start to 15 m	6.24 ± 0.17 [a]	7.52 ± 0.52 [b]	8.00 ± 0.29 [b]	7.97 ± 0.90 [b]
Block	0.77 ± 0.05 [a]	0.81 ± 0.07 [b]	0.91 ± 0.04 [b]	0.93 ± 0.13 [d]
Flight	0.60 ± 0.05 [a]	0.43 ± 0.10 [b]	0.54 ± 0.04 [c]	0.34 ± 0.14 [b]
Underwater	3.39 ± 0.77 [a]	2.72 ± 1.10 [b]	1.90 ± 0.73 [b]	2.25 ± 0.45 [b]
Free Swim	1.35 ± 0.66 [a]	3.15 ± 0.73 [b]	4.76 ± 0.56 [b]	3.93 ± 1.21 [b]
Distance (m)				
Entry	3.17 ± 0.48 [a]	2.94 ± 0.40 [a]	2.65 ± 0.09 [c]	2.61 ± 0.36 [c]
Underwater	8.87 ± 0.66 [a]	6.68 ± 1.26 [b]	4.36 ± 0.89 [b]	5.63 ± 1.74 [b]
Free Swim	2.96 ± 1.07 [a]	5.37 ± 1.39 [b]	7.82 ± 0.94 [b]	6.75 ± 2.10 [b]
Velocity (m/s)				
Underwater	2.69 ± 0.42 [a]	2.39 ± 0.29 [b]	1.86 ± 0.15 [c]	1.61 ± 0.43 [c]
Free Swim	2.38 ± 0.23 [a]	1.69 ± 0.52 [b]	1.73 ± 0.29 [b]	1.52 ± 0.90 [b]

Note. For each specific variable (e.g., start to 15 m), the same superscript letter indicates no significant difference ($P < .05$) within this specific variable, and a different letter indicates significant difference.

Lower trunk muscle activity during crawl swimming in a single leg amputee

- Successful crawl swimming depends on body roll along the longitudinal axe.
- Sufficient core trunk stability is needed to balance out the forces generated by the upper and lower extremities.
- Various theories on how a swimmer generates and controls the body roll.
  - From those theories it can be expected that a single leg amputee will show different result from a swimmer using both legs

Method

- One … mpic

…ıip

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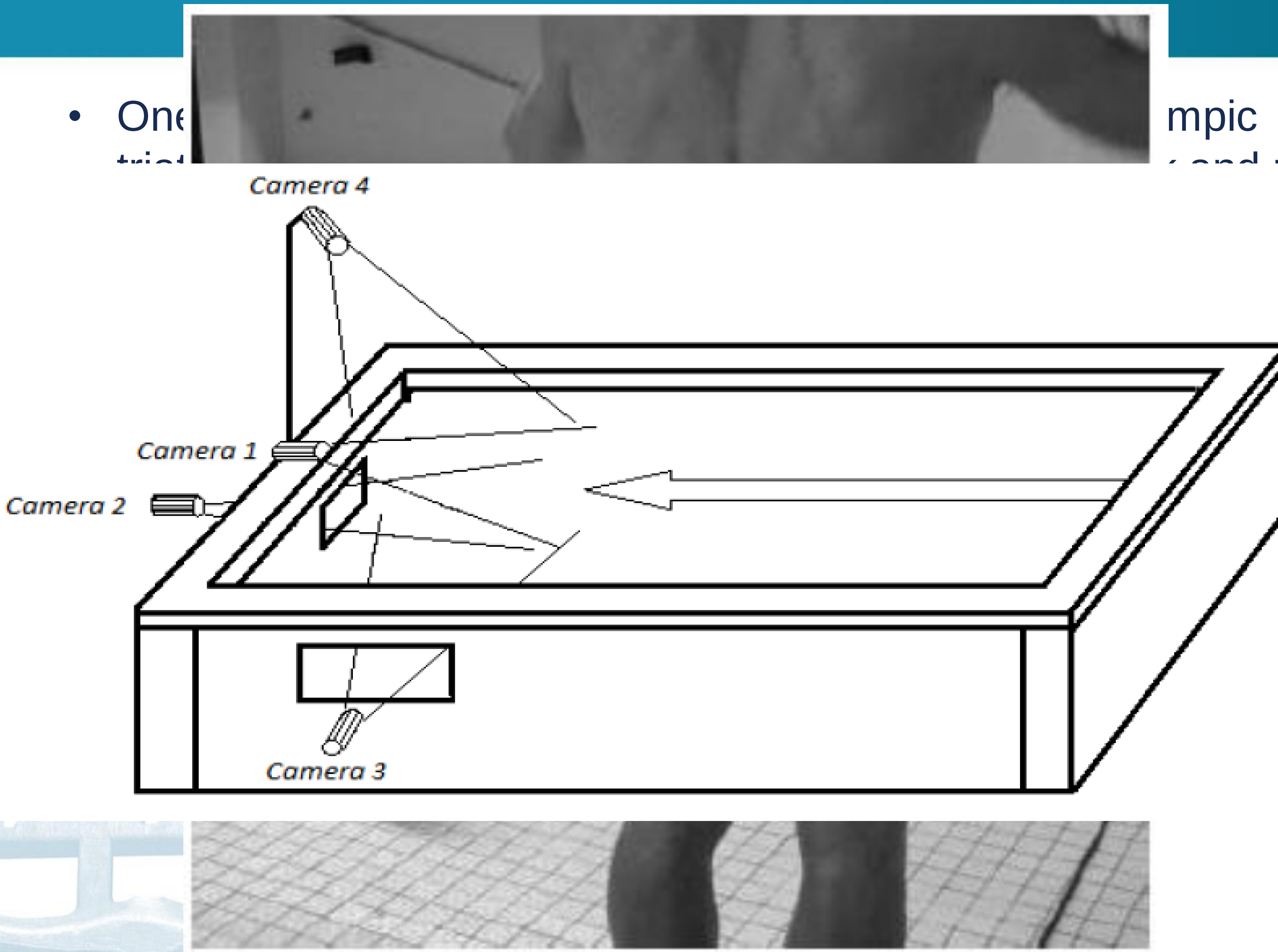
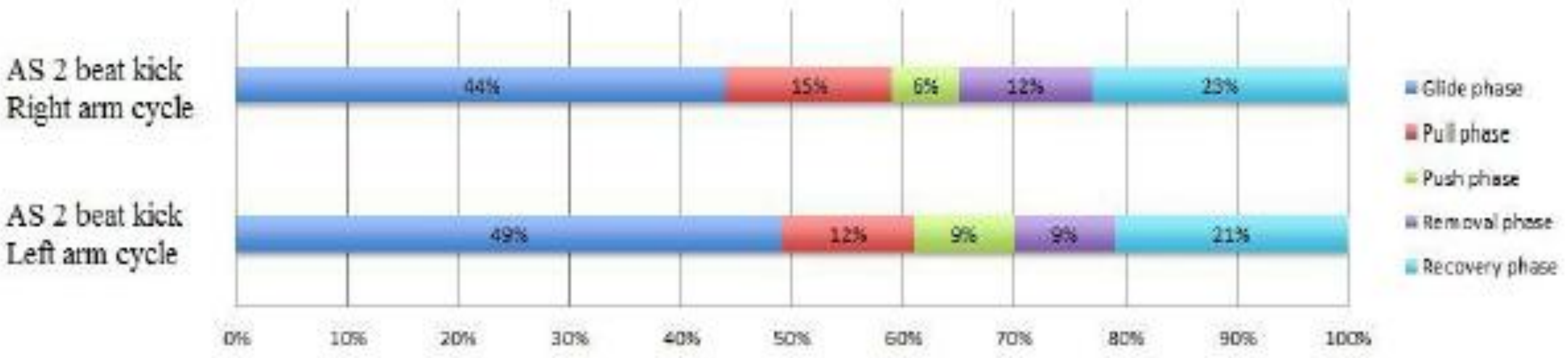
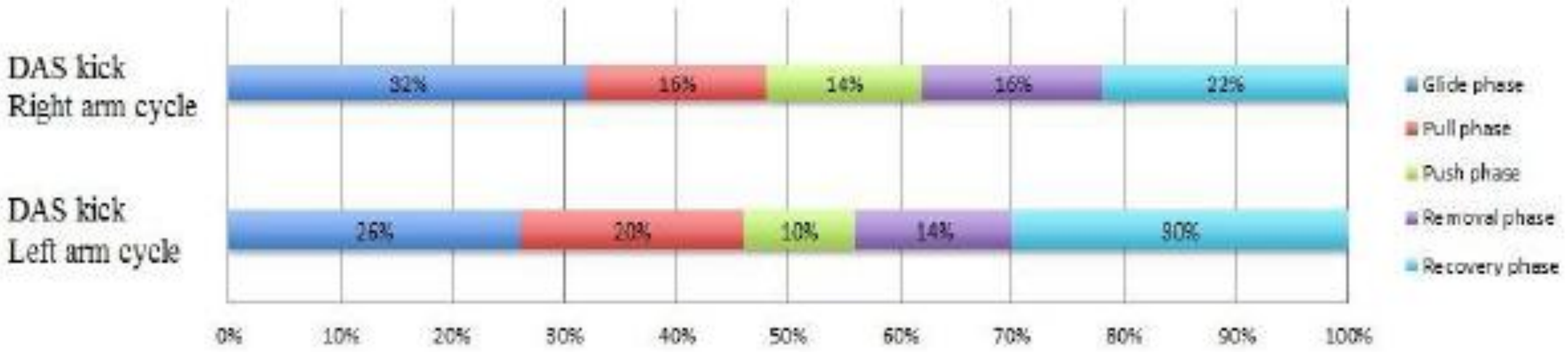


Result - arm cycles



Both swimmers had shorter glide to the opposite side of their preferred breathing side, even though they did not breath

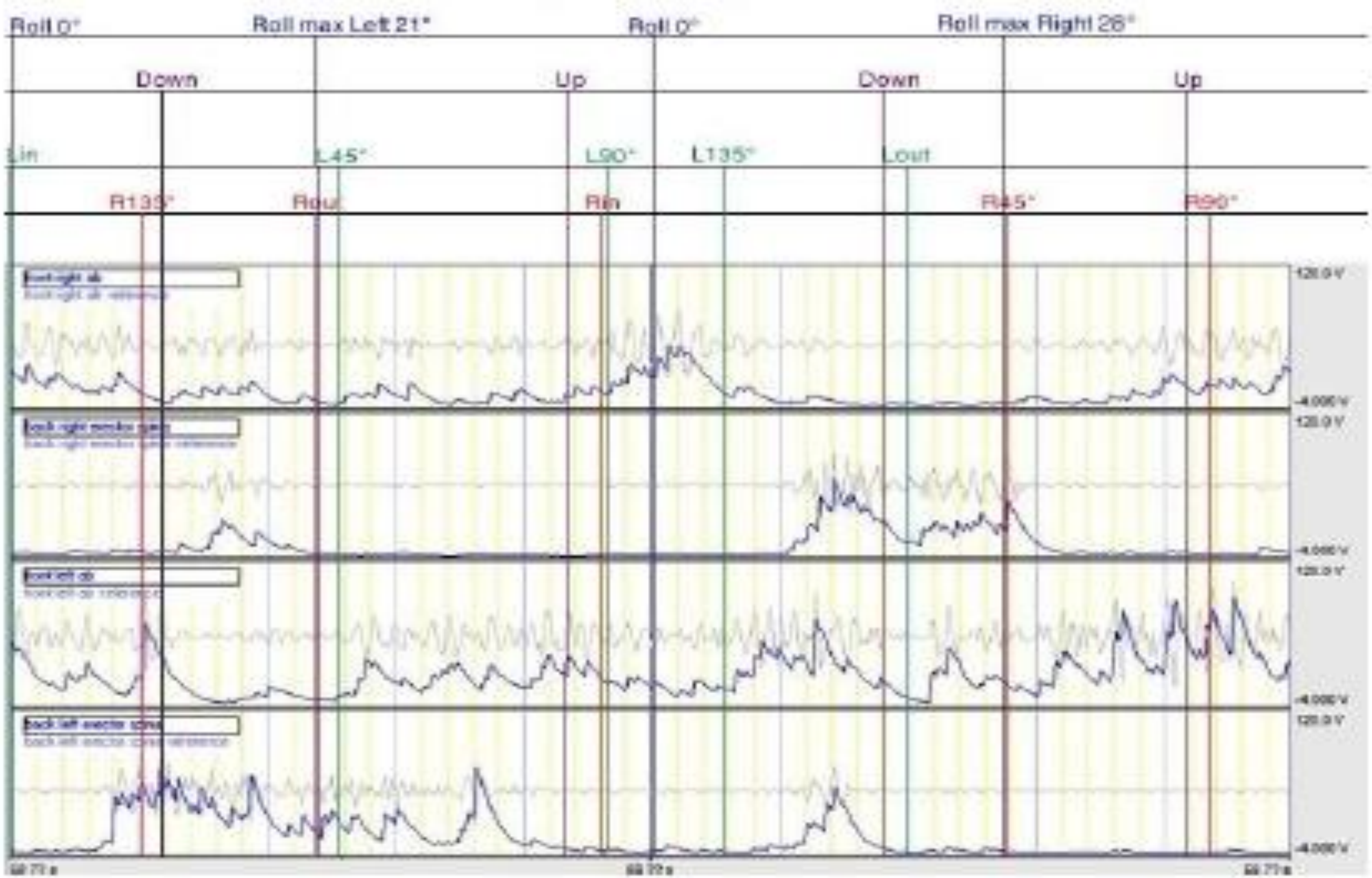


Results - body roll and muscle activity

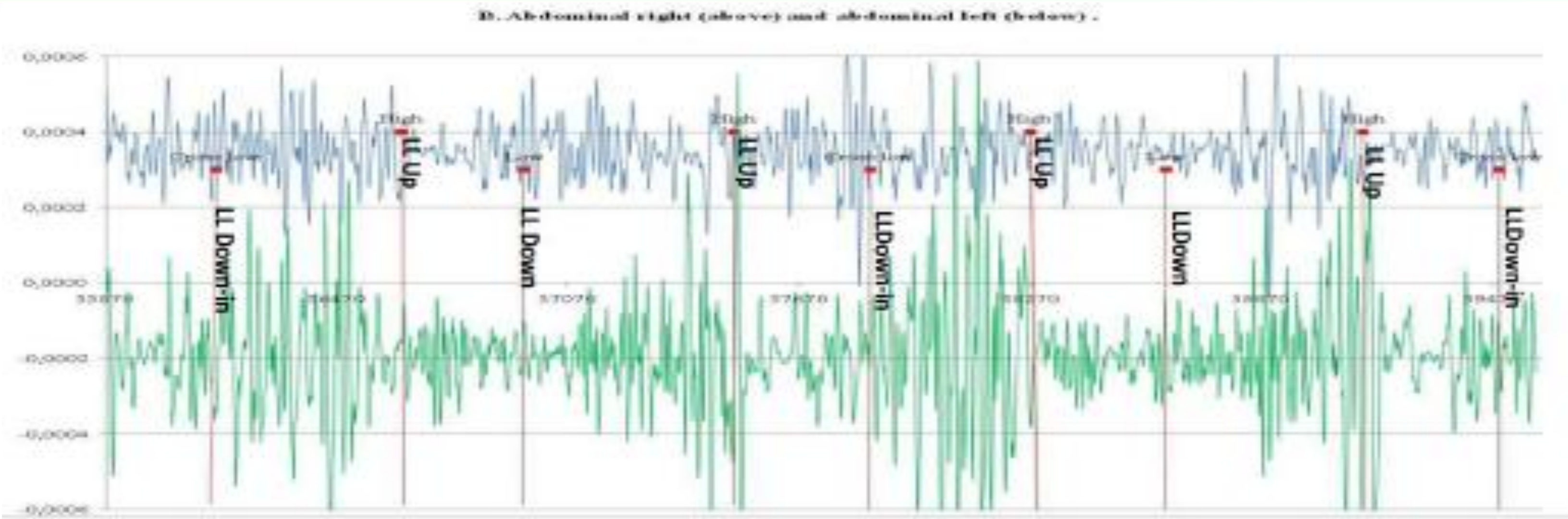
- Both swimmers roll less at highr speed
  - S9 swimmer rolls more to the right side (amputated side)
- S9
  - L26° - R50°   L21° - R28°
- Tri
  - L23° - R25°   L18° - R20°
- Clear muscle pattern is observed in ES for both swimmers but not so clearly in RA
  - More roll = more muscle activity in ES

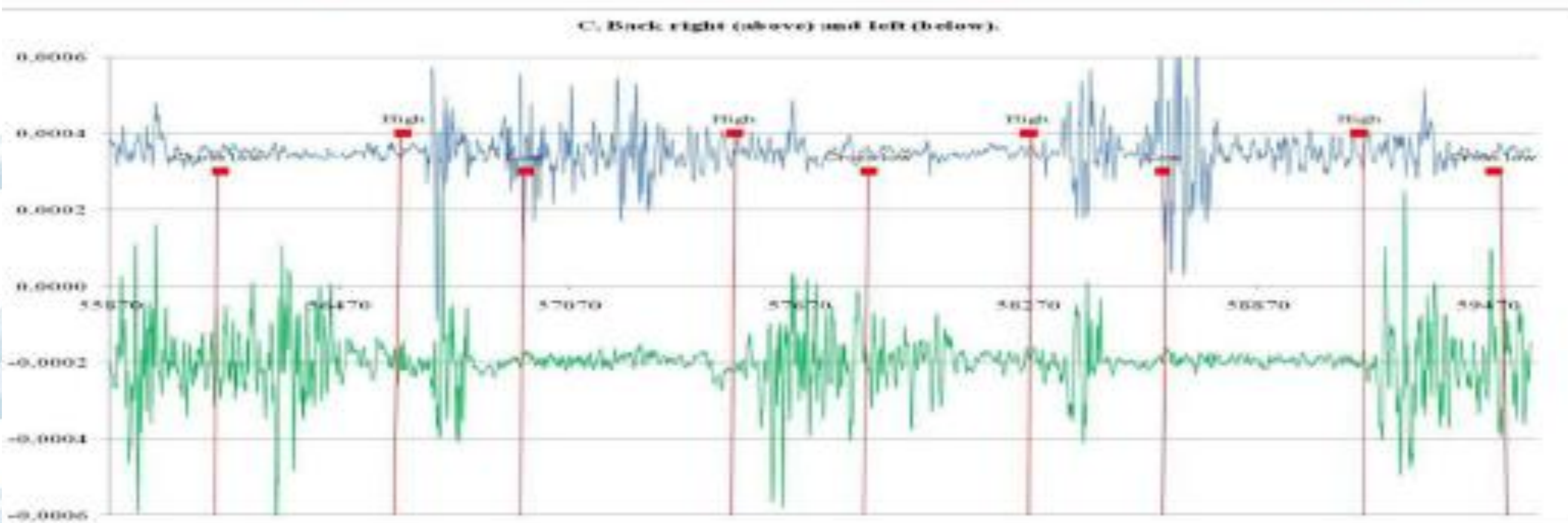
Results - body roll and muscle activity

EMG chart for S9



Result- raw EMG for S9

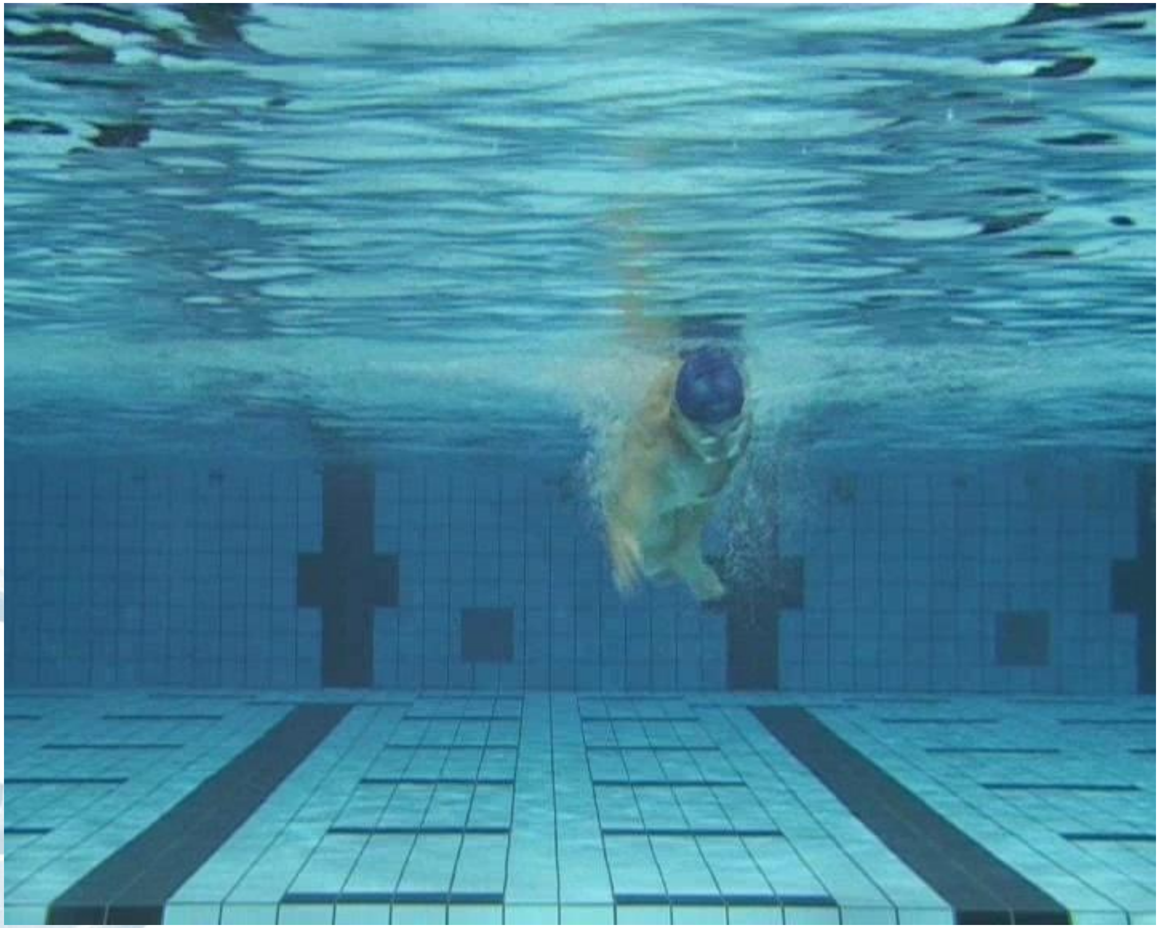




Discussion

- There is a clear difference between the amputee swimmer and the triathlon swimmer in:
  - Body roll, SR, cycle phases and muscle activity
- There are many good studies on single arm amputated swimmers, but fewer on single leg
- This study shows that there is clearly a room for research on these elite athletes

Is Competition: therapeutic???




Thank You

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- INAS-FID: International Sports Federation for Persons with Intellectual Disability
- International Paralympic Committee (& IPC Swimming)
- Veronique Colman(†) for Analysis help
- Bruce Mason for some data collection
- Coauthors: Laurie Malone, Brendan Burkett, Jonas Martens, Connor Osborough, Carl Payton, Robert Steadward

Important points to think about

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- In free and breast, the relation between start speed and end race result are highest in class S(B)6 where the greatest mix of in and out of water starters occurs.
- S(B)6 is, in fact, the only class in which start speed correlates with end race result in all strokes.
- It therefore seems reasonable to encourage all swimmers to use a block start when possible.
- Systematic check of the start time by the coach will of course indicate what is best for each particular swimmer.

Important points

- In the functional classification system, the same number of points is given to starting and turning. But as race distance increases, the number of turn’s increases but there is always only one start.
- A new classification system for distance freestyle events could therefore be suggested.

- Evaluation of performance serves to combine similar classes and reduce the number of winners enhancing the strength of competition and maintain fairness. It becomes easier to arrange competition programs.
- Without careful consideration and research, the combination of classes may prompt some swimmers to drop out or retire immediately because they feel unfairly penalized.
- Decreasing the number of classes increases the numbers in each class and the potential for differences between swimmers. All the swimmers in a class however must theoretically have a similar chance to win.

1. Increases in SS were achieved by a 5% increase in SF coinciding with a 2% decrease in SL.
2. At SSmax, SF was significantly related to SS ($r = 0.72$) whereas SL was not.
3. Faster swimmers did not necessarily use longer and slower strokes to swim at a common sub-maximal speed when compared to their slower counterparts.
4. No correlations existed between SL and any anthropometric characteristics.
5. Bi-acromial breadth, shoulder girth and upper-arm length significantly correlated with the SF at SSmax.

6. IdCadapt did not change with an increase in swimming speed up to max. (catch-up model).
7. All swimmers showed significantly more catch-up before their affected-arm pull compared to their unaffected-arm pull.
8. At SSmax, the fastest swimmers used higher SF and less catch-up before their affected-arm pull, compared to the slower swimmers.

General Conclusion

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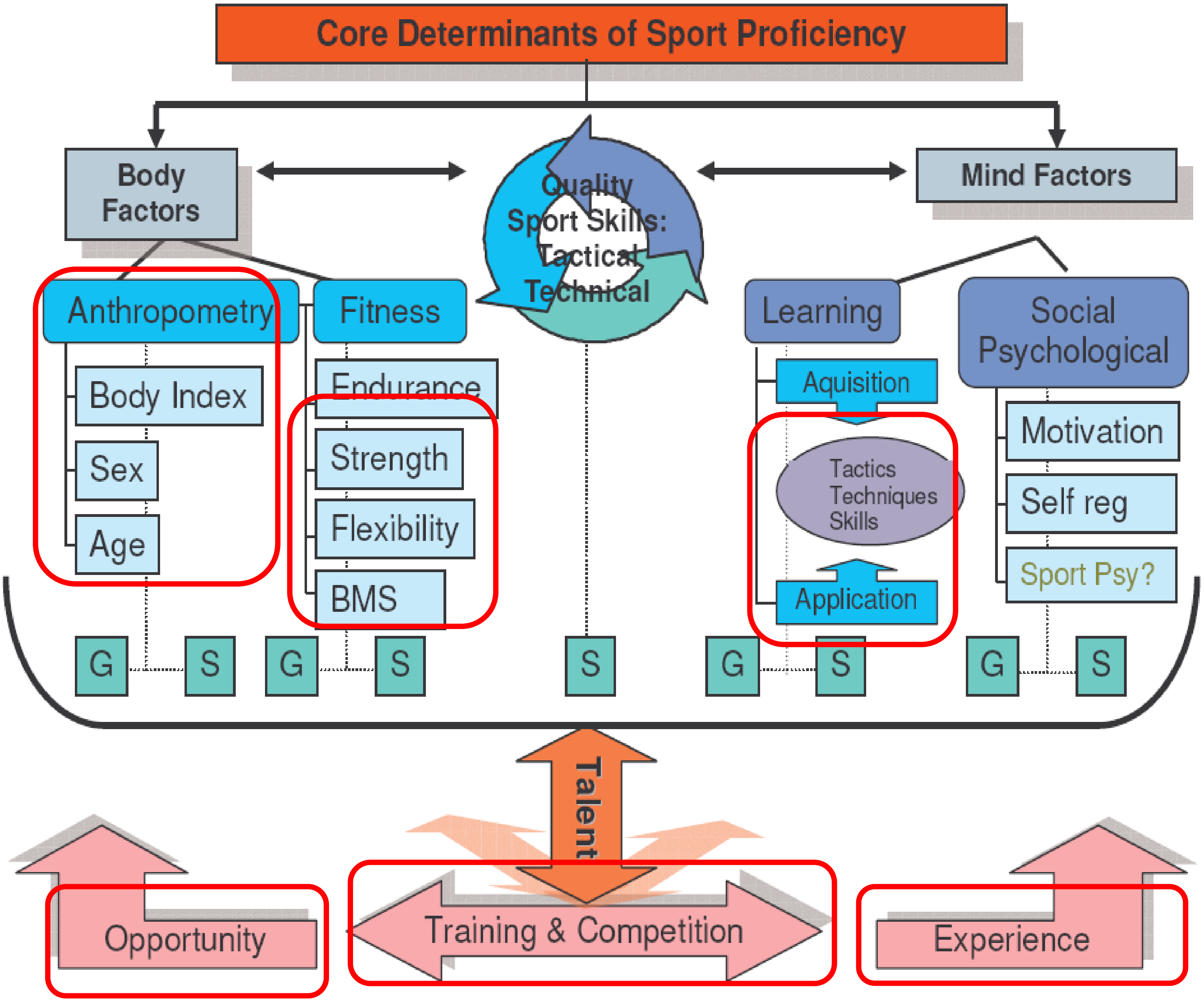
Few differences between how able bodied and Paralympic swimmers win the race

Within considerations of
boarders and overlapping
the classification system does the job

Other Variables ?

- Swim Straight
- Stroke count in turns
- Block Reaction at Start
- Breathing Strategy
- Relaxation and Rhythm
- ???



Core Determinants of Sport Proficiency
Body Factors
Quality Sport Skills: Tactical Technical
Mind Factors
Anthropometry
Fitness
Learning
Social Psychological
Body Index
Sex
Age
Endurance
Strength
Flexibility
BMS
Aquisition
Tactics Techniques Skills
Application
Motivation
Self reg
Sport Psy?
G
S
G
S
S
G
S
G
S
Talent
Opportunity
Training & Competition
Experience