Identification of Muscle Fitness Standards for Exploration Mission Tasks

NASA Muscle Strength Standard

NASA TECHNICAL STANDARD	NASA-STD-3001, VOLUME 1, Revision A w/Change 1
National Aeronautics and Space Administration Washington, D.C. 20546-0001	**Approved:** 07-30-2014 **Superseding** NASA-STD-3001, Volume 1 **Change 1 Approved:** 02-12-2015

NASA SPACE FLIGHT HUMAN-SYSTEM STANDARD

VOLUME 1, REVISION A: CREW HEALTH

MEASUREMENT SYSTEM IDENTIFICATION: NONE

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Purpose: to generate an evidence base to inform an update to the NASA muscle strength standard that is linked the performance of space exploration tasks.

4.2.8 Permissible Outcome Limit for Muscle Strength Standard

4.2.8.1 Pre-flight muscle strength and function shall be within normal values for age and sex of the astronaut population.

4.2.8.2 Countermeasures shall maintain in-flight skeletal muscle strength at or above 80 percent of baseline values.

4.2.8.3 Post-flight reconditioning shall be aimed at returning to baseline muscle strength.

Task Selection

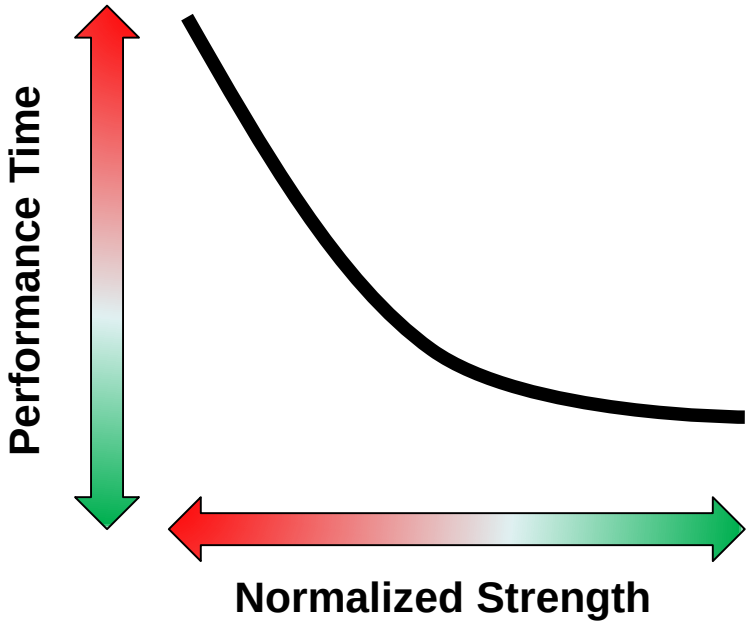
Four benchmark tasks were vetted through NASA stakeholders and approved by the NASA Human Systems Risk Board.

- Unaided top hatch capsule egress
- Ambulation and supply transfer
- Incapacitated crewmember rescue
- Hill climb and descent

Specific Aims

- Characterize the relationship between strength and exploration task performance time.
- Identify which test best (or acceptably) predict task performance.
- Identify strength thresholds below which task performance is impaired.

Strategic Approach



- Mock up selected tasks
- Perform baseline measurements of strength
- Perform tasks under different loaded conditions
- Plot *normalized* strength versus performance time
- Identify strength thresholds

Strength/Body Weight Approach

Baseline	Atrophy / Detraining	Weighted Suit
$\frac{\text{Strength}}{\text{Weight}}$	$\frac{\text{Strength}}{\text{Weight}}$	$\frac{\text{Strength}}{\text{Weight}}$
↔	↓	↓

Task trials were performed with the addition of ”0”, 20, 40, 60, 80% of body weight.

Strength metrics normalized to total load for data analyses.

Increases the number of observations.

Increases the observed strength range.

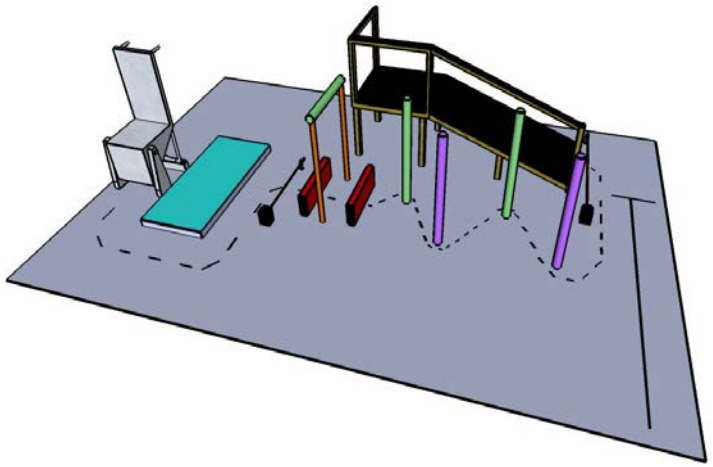
Previous Work

Eur J Appl Physiol (2013) 113:911–921
DOI 10.1007/s00421-012-2500-z

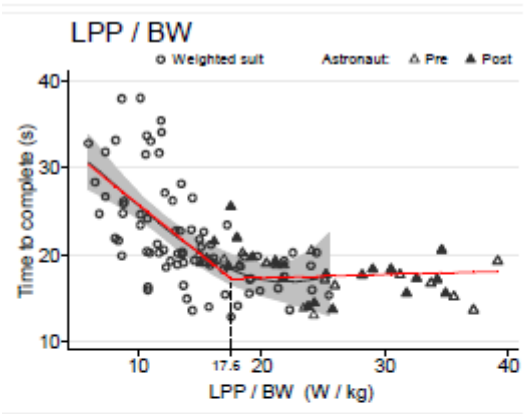
ORIGINAL ARTICLE

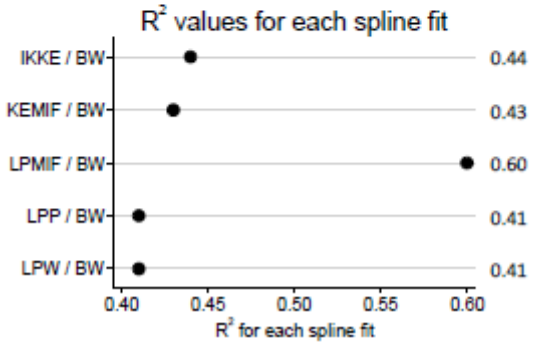
Influence of muscle strength to weight ratio on functional task performance

Jeffrey W. Ryder · Roxanne E. Buxton · Elizabeth Goetchius · Melissa Scott-Pandorf · Kyle J. Hackney · James Fiedler · Robert J. Ploutz-Snyder · Jacob J. Bloomberg · Lori L. Ploutz-Snyder



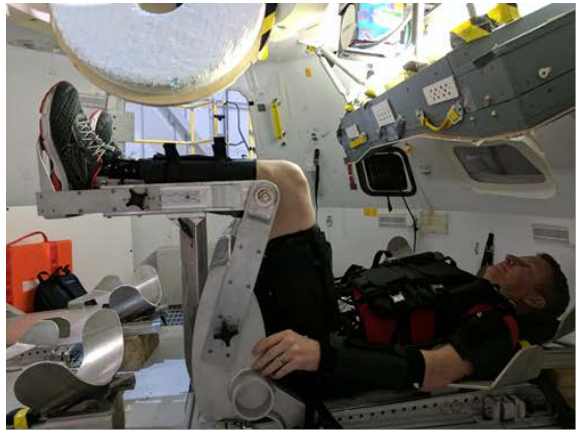
Seat Egress Test

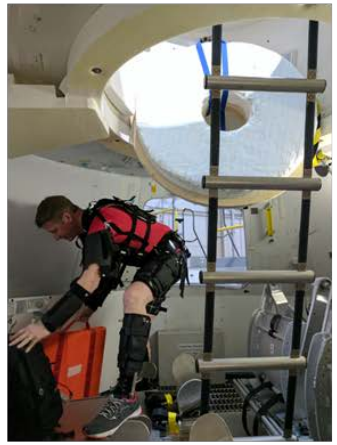




Two Slope Spline Regression

Capsule Egress





Ambulation and Supply Transfer

1.5 km walk on a 50 m rubber mulch track, transfer 30 bags (10.9 kg each) between platforms 5 m apart.

Incapacitated Crewmember Rescue

Move 75 kg rescue dummy onto a rescue sled

Drag 50 meters

Hill Climb and Descent

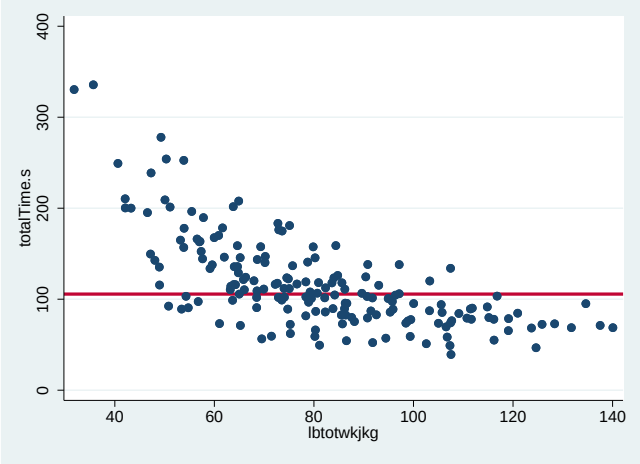
Climb hill (1000m with a 40m rise) with 4.5 kg bar

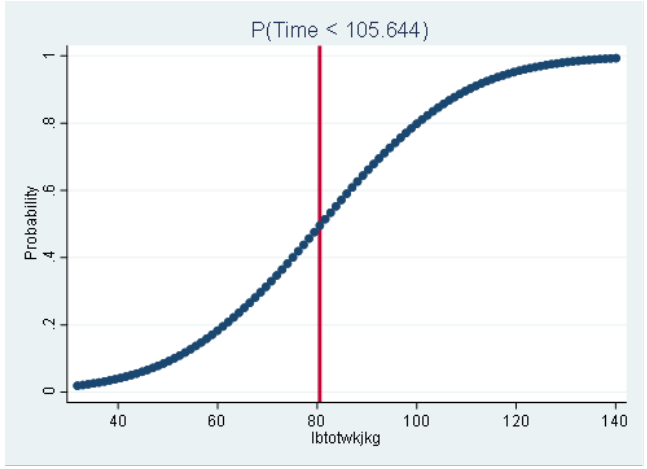
Return (no bar)

Probability-based Statistical Model

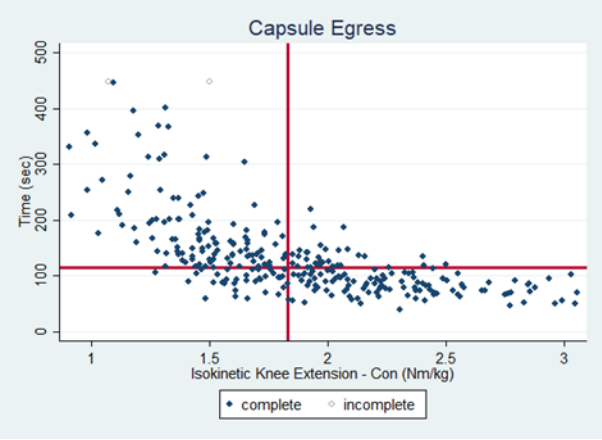
The model identifies a minimal threshold for achieving acceptable performance

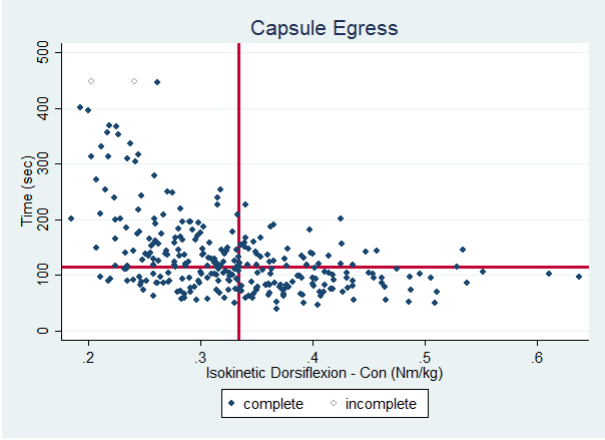
- Acceptable is defined as median or better based on current data.
- Takes task failures into account.
- Takes random differences between subjects into account.
- Subjects with strength above the thresholds tend to perform the task to about the same level of performance.
- Diminishing return per increase in strength after the inflection point of the probability curve.

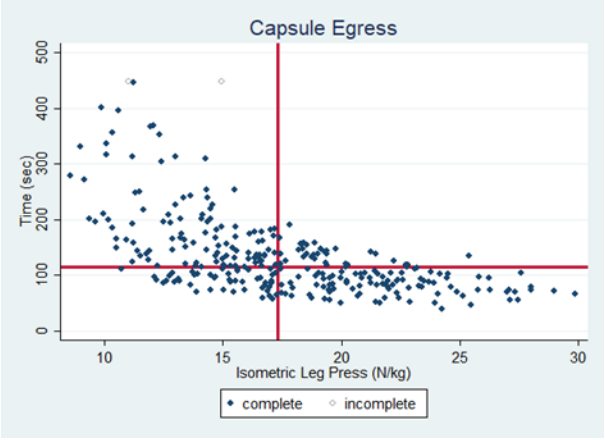


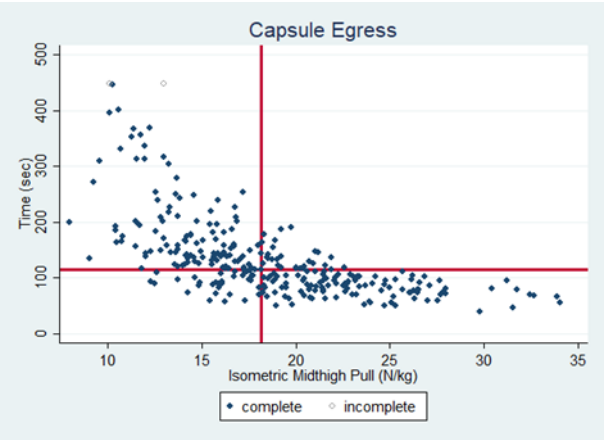


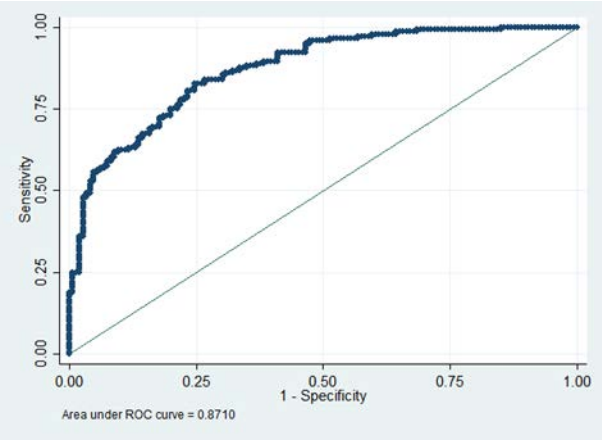
Capsule Egress Results

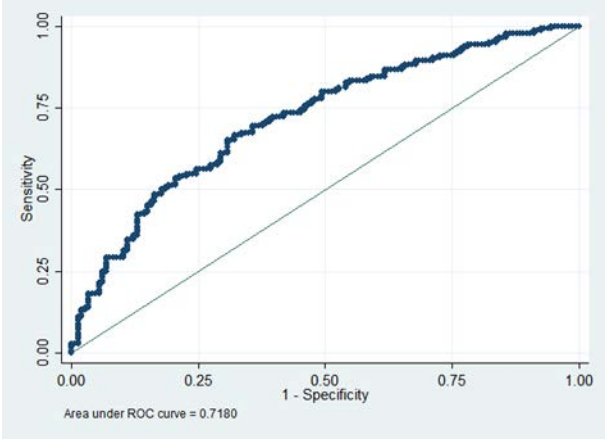


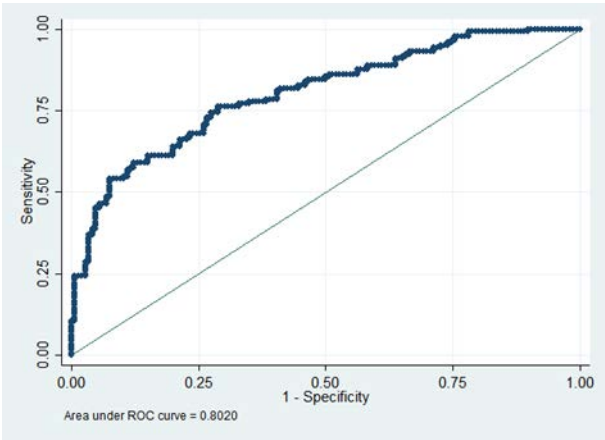


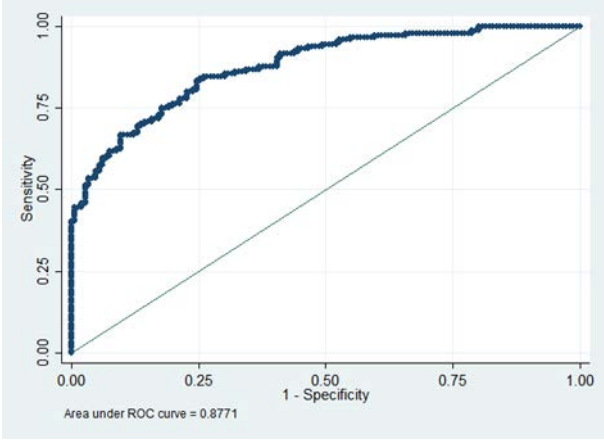












ROC Distribution

		Egress	Ambulation	Rescue	Hill Climb
	Excellent (0.90 – 1.00)			1	
	Good (0.80 – 0.89)	19	18	9	19
	Fair (0.70 – 0.79)	3	4	10	3
	Poor (0.60 – 0.69)			2	
	Fail (< 0.60)				

Threshold Strength Values

Isokinetic Battery

Test	Egress	Rescue	Ambulation	Hill Climb
Knee Extension Torque (Nm/kg)	1.83	1.83	1.83	1.86
Knee Flexion Torque (Nm/kg)	0.93	0.93	0.93	0.94
Knee Extension Work (J/kg)	22.90	22.84	22.98	23.34
Knee Flexion Work (J/kg)	12.78	12.75	12.85	12.98
Plantar Flexion Torque (Nm/kg)	1.21	1.21	1.21	1.22
Dorsiflexion Torque (Nm/kg)	0.33	0.33	0.33	0.33

Threshold Strength Values

Muscle Performance Battery

Test	Egress	Rescue	Ambulation	Hill Climb
Leg Press Strength (N/kg)	17.36	17.30	17.51	17.65
Leg Press Power (W/kg)	14.82	14.80	14.91	15.10
Leg Press Work (J/kg)	74.73	73.81	75.55	76.76
Bench Press Strength (N/kg)	6.40	6.39	6.57	6.67
Bench Press Power (W/kg)	6.22	6.26	6.41	6.49
Bench Press Work (J/kg)	25.26	25.08	26.11	26.50
Isometric Mid-thigh Pull (N/kg)	18.12	18.20	18.36	18.53

Application of Thresholds

Absolute strength needed for 75 kg person to meet 17.4 N/kg leg press*

	Earth	Moon	Mars
Shirt Sleeve	1305 (293)	218 (49)	489 (110)
12.5 kg L&E suit	1522 (342)	254 (57)	571 (128)
65 kg EVA suit	2436 (548)	406 (91)	914 (205)

*Accounts for gravity and suit weight. Does not account for factors such as resistance about suit joints.

Conclusions

Most of the evaluated strength measures are suitable for use as standards. There is flexibility for situational needs and operational capabilities to be taken into account without major compromise to the quality of the standard.

Thresholds were consistent across the selected tasks.

Thresholds suggest ample strength reserve for task completion.

Thank You!

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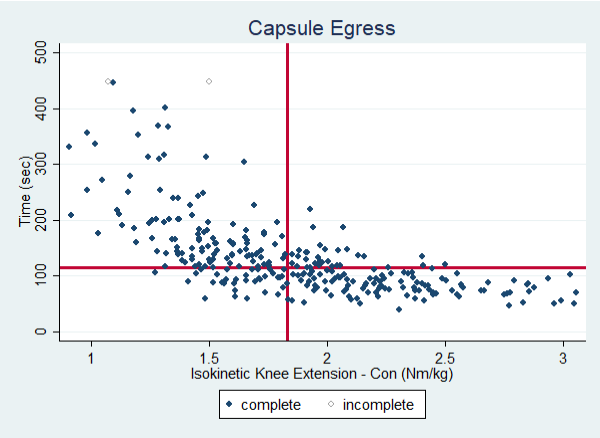
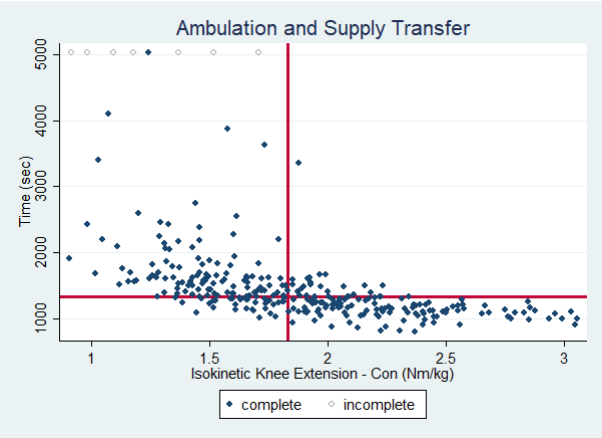
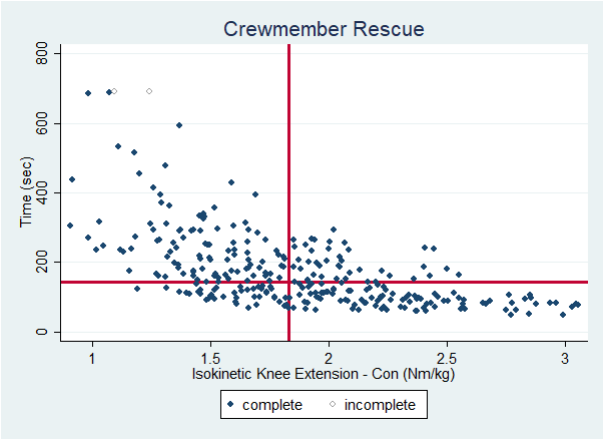
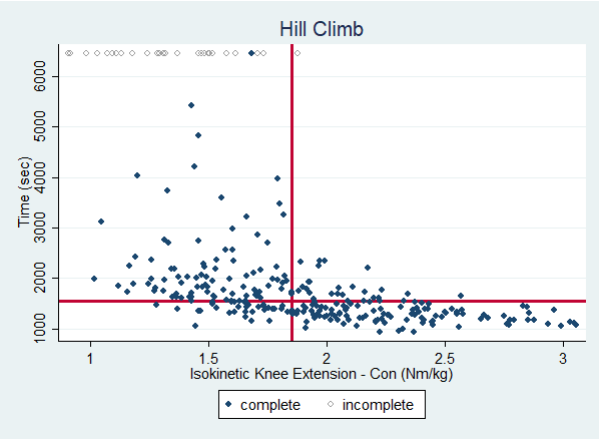
Back-up

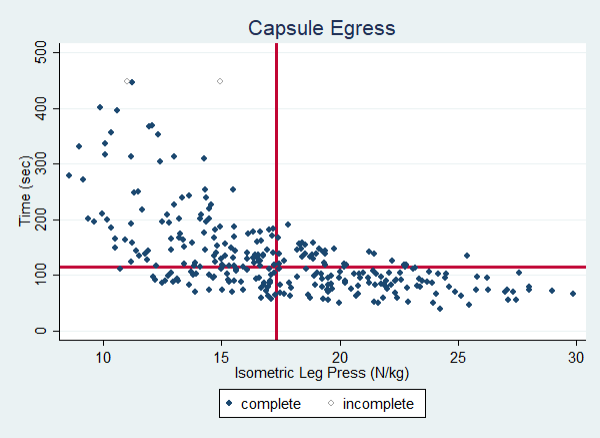
Failures

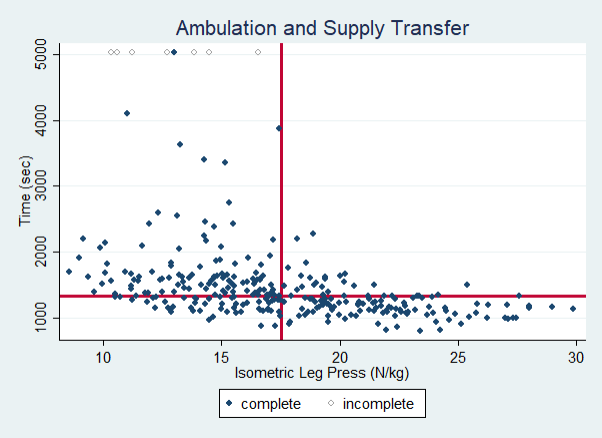

Capsule Egress
Time (sec)
0
100
200
300
400
500
1
1.5
2
2.5
3
Isokinetic Knee Extension - Con (Nm/kg)
complete
incomplete

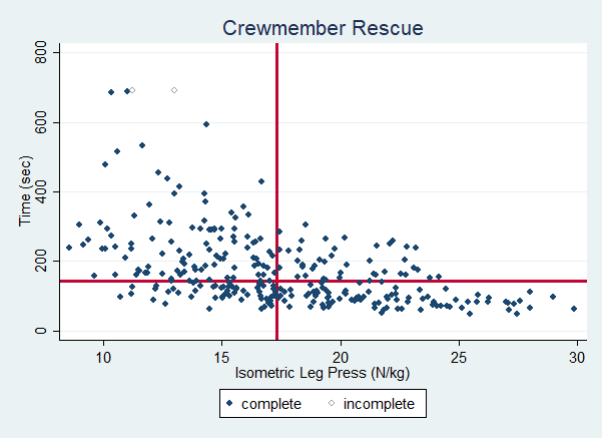

Ambulation and Supply Transfer
Time (sec)
1000
2000
3000
4000
5000
1
1.5
2
2.5
3
Isokinetic Knee Extension - Con (Nm/kg)
complete
incomplete

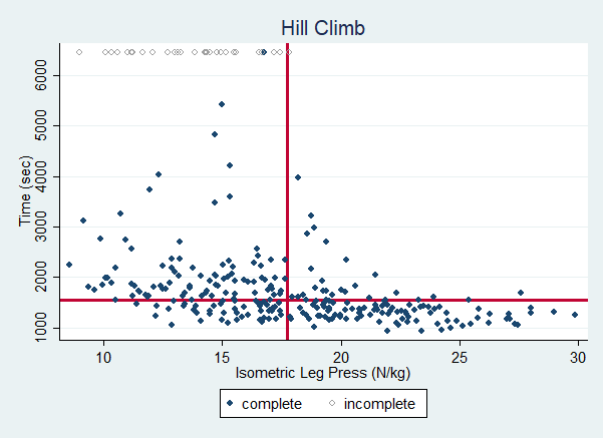

Crewmember Rescue
Time (sec)
0
200
400
600
800
1
1.5
2
2.5
3
Isokinetic Knee Extension - Con (Nm/kg)
complete
incomplete


Hill Climb
Time (sec)
1000
2000
3000
4000
5000
6000
1
1.5
2
2.5
3
Isokinetic Knee Extension - Con (Nm/kg)
complete
incomplete

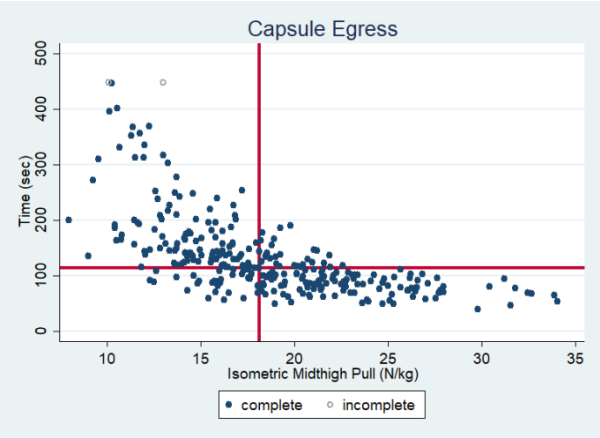

Capsule Egress
Time (sec)
0
100
200
300
400
500
10
15
20
25
30
Isometric Leg Press (N/kg)
complete
incomplete

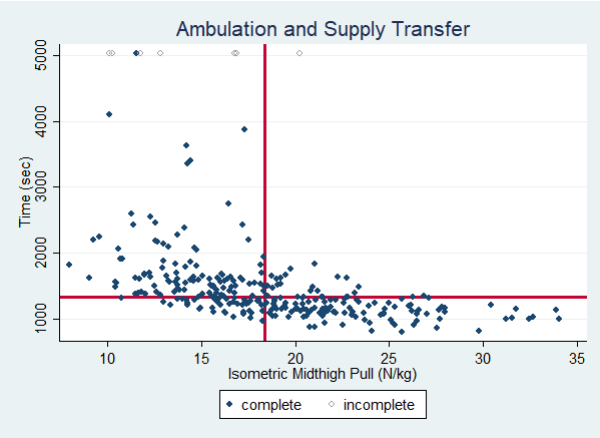

Ambulation and Supply Transfer
Time (sec)
1000
2000
3000
4000
5000
10
15
20
25
30
Isometric Leg Press (N/kg)
complete
incomplete


Crewmember Rescue
Time (sec)
0
200
400
600
800
10
15
20
25
30
Isometric Leg Press (N/kg)
complete
incomplete


Hill Climb
Time (sec)
1000
2000
3000
4000
5000
6000
10
15
20
25
30
Isometric Leg Press (N/kg)
complete
incomplete

Failures


Capsule Egress
Time (sec)
Isometric Midthigh Pull (N/kg)
complete
incomplete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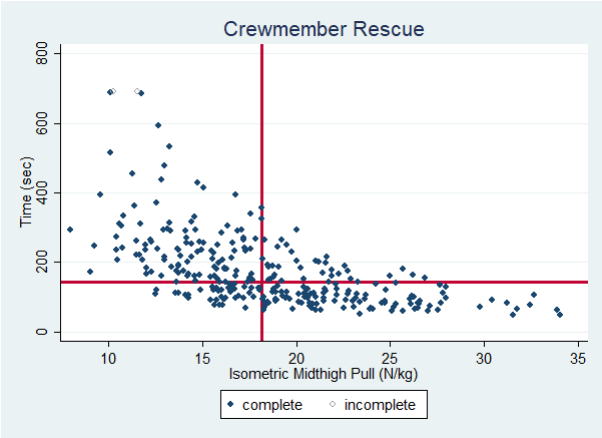
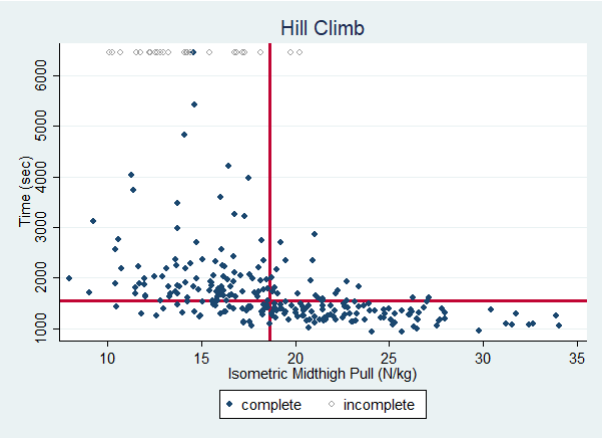
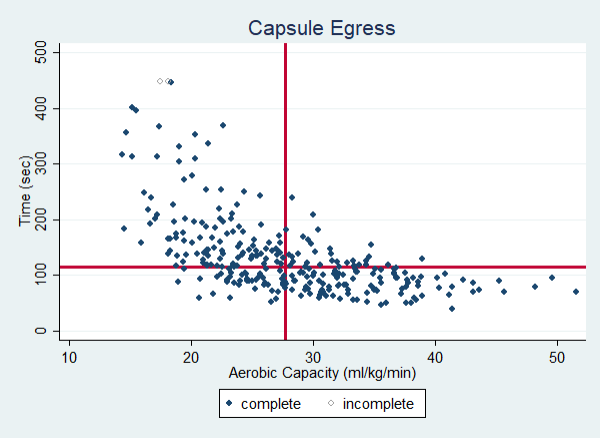
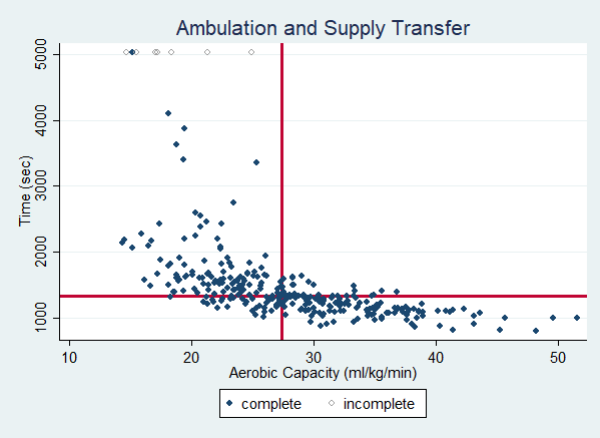
Time (sec)
Isometric Midthigh Pull (N/kg)
complete
incomplete


Crewmember Rescue
Time (sec)
Isometric Midthigh Pull (N/kg)
complete
incomplete


Hill Climb
Time (sec)
Isometric Midthigh Pull (N/kg)
complete
incomplete


Capsule Egress
Time (sec)
Aerobic Capacity (ml/kg/min)
complete
incomplete


Ambulation and Supply Transfer
Time (sec)
Aerobic Capacity (ml/kg/min)
complete
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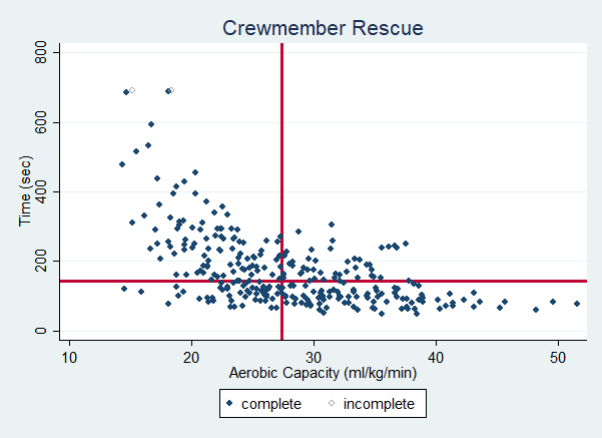
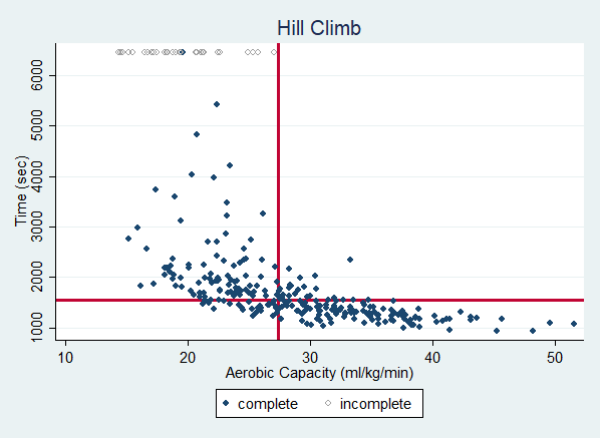

Crewmember Rescue
Time (sec)
Aerobic Capacity (ml/kg/min)
complete
incomplete


Hill Climb
Time (sec)
Aerobic Capacity (ml/kg/min)
complete
incomplete

Subject Characteristics

Physiological Measure	Mean ± SD	Range
Age (years)	37 ± 7	24 -52
Weight (kg)	75.0 ± 13.3	52.7 -112.2
Height (m)	1.73 ± 0.10	1.52 – 1.93
Isokinetic Knee Extension - Con (Nm kg^{-1})	2.56 ± 0.47	1.66 – 3.53
Isokinetic Knee Extension - Ecc (Nm kg^{-1})	3.35 ± 0.72	1.52 – 5.01
Isokinetic Knee Flexion - Con (Nm kg^{-1})	1.29 ± 0.26	0.86 – 2.01
Isokinetic Knee Flexion - Ecc (Nm kg^{-1})	1.95 ± 0.35	1.15 – 2.98
Isokinetic Knee Extension Work (J kg^{-1})	32.09 ± 5.78	20.88 – 44.61
Isokinetic Knee Flexion Work (J kg^{-1})	17.85 ± 3.50	10.73 – 26.09
Isokinetic Plantarflexion - Con (Nm kg^{-1})	1.68 ± 0.30	1.05 – 2.19
Isokinetic Plantarflexion - Ecc (Nm kg^{-1})	2.45 ± 0.55	1.12 – 3.58
Isokinetic Dorsiflexion - Con (Nm kg^{-1})	0.45 ± 0.08	0.32 – 0.75
Isokinetic Dorsiflexion - Ecc (Nm kg^{-1})	0.80 ± 0.11	0.56 – 1.06
Isokinetic Trunk Extension (Nm kg^{-1})	5.27 ± 1.04	3.04 – 8.03
Isokinetic Trunk Flexion (Nm kg^{-1})	2.60 ± 0.51	1.53 – 3.51
Isometric Leg Press (N kg^{-1})	24.12 ± 4.56	15.84 – 33.31
Leg Press Power (W kg^{-1})	20.61 ± 4.35	10.67 – 28.23
Leg Press Work (J kg^{-1})	104.56 ± 24.25	58.28 – 161.97
Isometric Bench Press (N kg^{-1})	8.98 ± 3.04	4.24 – 16.34
Bench Press Power (W kg^{-1})	8.71 ± 2.78	3.94 – 15.30
Bench Press Work (J kg^{-1})	35.61 ± 12.61	17.82 – 57.73
Isometric Midthigh Pull (N kg^{-1})	25.50 ± 5.51	14.00 – 37.79
Isometric Knee Extension (N kg^{-1})	7.68 ± 1.78	4.84 – 12.67
Vertical Jump Power (W kg^{-1})	43.50 ± 8.57	27.80 – 61.85
Wingate Power (W kg^{-1})	8.03 ± 1.62	4.47 – 11.16
Aerobic Capacity (ml kg^{-1} min^{-1})	38.37 ± 7.44	25.80 – 59.7

Results - Contingency Tasks

Capsule Egress

Predictor Variable	Threshold	ROC
Isokinetic Knee Extension - Con (Nm kg^{-1})	1.83	0.87
Isokinetic Knee Extension - Ecc (Nm kg^{-1})	2.38	0.84
Isokinetic Knee Flexion - Con (Nm kg^{-1})	0.93	0.83
Isokinetic Knee Flexion - Ecc (Nm kg^{-1})	1.40	0.80
Isokinetic Knee Extension Work (J kg^{-1})	22.90	0.87
Isokinetic Knee Flexion Work (J kg^{-1})	12.78	0.84
Isokinetic Plantarflexion - Con (Nm kg^{-1})	1.21	0.83
Isokinetic Plantarflexion - Ecc (Nm kg^{-1})	1.76	0.83
Isokinetic Dorsiflexion - Con (Nm kg^{-1})	0.33	0.72
Isokinetic Dorsiflexion - Ecc (Nm kg^{-1})	0.58	0.76
Isokinetic Trunk Extension (Nm kg^{-1})	3.79	0.83
Isokinetic Trunk Flexion (Nm kg^{-1})	1.88	0.78
Isometric Leg Press (N kg^{-1})	17.36	0.80
Leg Press Power (W kg^{-1})	14.82	0.86
Leg Press Work (J kg^{-1})	74.73	0.85
Isometric Bench Press (N kg^{-1})	6.40	0.84
Bench Press Power (W kg^{-1})	6.22	0.82
Bench Press Work (J kg^{-1})	25.26	0.85
Isometric Midthigh Pull (N kg^{-1})	18.12	0.88
Isometric Knee Extension (N kg^{-1})	5.44	0.85
Vertical Jump Power (W kg^{-1})	31.16	0.84
Wingate Power (W kg^{-1})	5.74	0.82
Aerobic Capacity (ml kg^{-1} min^{-1})	27.57	0.84

Rescue

Predictor Variable	Threshold	ROC
Isokinetic Knee Extension - Con (Nm kg^{-1})	1.83	0.79
Isokinetic Knee Extension - Ecc (Nm kg^{-1})	2.40	0.78
Isokinetic Knee Flexion - Con (Nm kg^{-1})	0.93	0.78
Isokinetic Knee Flexion - Ecc (Nm kg^{-1})	1.40	0.76
Isokinetic Knee Extension Work (J kg^{-1})	22.84	0.82
Isokinetic Knee Flexion Work (J kg^{-1})	12.75	0.81
Isokinetic Plantarflexion - Con (Nm kg^{-1})	1.21	0.73
Isokinetic Plantarflexion - Ecc (Nm kg^{-1})	1.76	0.78
Isokinetic Dorsiflexion - Con (Nm kg^{-1})	0.33	0.68
Isokinetic Dorsiflexion - Ecc (Nm kg^{-1})	0.58	0.72
Isokinetic Trunk Extension (Nm kg^{-1})	3.78	0.79
Isokinetic Trunk Flexion (Nm kg^{-1})	1.90	0.67
Isometric Leg Press (N kg^{-1})	17.30	0.74
Leg Press Power (W kg^{-1})	14.80	0.82
Leg Press Work (J kg^{-1})	73.81	0.87
Isometric Bench Press (N kg^{-1})	6.39	0.88
Bench Press Power (W kg^{-1})	6.26	0.83
Bench Press Work (J kg^{-1})	25.08	0.90
Isometric Midthigh Pull (N kg^{-1})	18.20	0.82
Isometric Knee Extension (N kg^{-1})	5.34	0.79
Vertical Jump Power (W kg^{-1})	31.12	0.81
Wingate Power (W kg^{-1})	5.68	0.84
Aerobic Capacity (ml kg^{-1} min^{-1})	27.41	0.75

Results - Nominal Tasks

Ambulation

Predictor Variable	Threshold	ROC
Isokinetic Knee Extension - Con (Nm kg^{-1})	1.83	0.88
Isokinetic Knee Extension - Ecc (Nm kg^{-1})	2.41	0.82
Isokinetic Knee Flexion - Con (Nm kg^{-1})	0.93	0.84
Isokinetic Knee Flexion - Ecc (Nm kg^{-1})	1.41	0.83
Isokinetic Knee Extension Work (J kg^{-1})	22.98	0.89
Isokinetic Knee Flexion Work (J kg^{-1})	12.85	0.85
Isokinetic Plantarflexion - Con (Nm kg^{-1})	1.21	0.84
Isokinetic Plantarflexion - Ecc (Nm kg^{-1})	1.77	0.85
Isokinetic Dorsiflexion - Con (Nm kg^{-1})	0.33	0.80
Isokinetic Dorsiflexion - Ecc (Nm kg^{-1})	0.57	0.83
Isokinetic Trunk Extension (Nm kg^{-1})	3.80	0.84
Isokinetic Trunk Flexion (Nm kg^{-1})	1.88	0.81
Isometric Leg Press (N kg^{-1})	17.51	0.78
Leg Press Power (W kg^{-1})	14.91	0.84
Leg Press Work (J kg^{-1})	75.55	0.82
Isometric Bench Press (N kg^{-1})	6.57	0.75
Bench Press Power (W kg^{-1})	6.41	0.75
Bench Press Work (J kg^{-1})	26.11	0.76
Isometric Midthigh Pull (N kg^{-1})	18.36	0.84
Isometric Knee Extension (N kg^{-1})	5.43	0.85
Vertical Jump Power (W kg^{-1})	31.46	0.80
Wingate Power (W kg^{-1})	5.78	0.83
Aerobic Capacity (ml kg^{-1} min^{-1})	27.40	0.88

Hill Climb

Predictor Variable	Threshold	ROC
Isokinetic Knee Extension - Con (Nm kg^{-1})	1.86	0.87
Isokinetic Knee Extension - Ecc (Nm kg^{-1})	2.44	0.80
Isokinetic Knee Flexion - Con (Nm kg^{-1})	0.94	0.86
Isokinetic Knee Flexion - Ecc (Nm kg^{-1})	1.43	0.83
Isokinetic Knee Extension Work (J kg^{-1})	23.34	0.86
Isokinetic Knee Flexion Work (J kg^{-1})	12.98	0.87
Isokinetic Plantarflexion - Con (Nm kg^{-1})	1.22	0.88
Isokinetic Plantarflexion - Ecc (Nm kg^{-1})	1.78	0.85
Isokinetic Dorsiflexion - Con (Nm kg^{-1})	0.33	0.85
Isokinetic Dorsiflexion - Ecc (Nm kg^{-1})	0.58	0.88
Isokinetic Trunk Extension (Nm kg^{-1})	3.84	0.85
Isokinetic Trunk Flexion (Nm kg^{-1})	1.89	0.84
Isometric Leg Press (N kg^{-1})	17.65	0.81
Leg Press Power (W kg^{-1})	15.10	0.84
Leg Press Work (J kg^{-1})	76.76	0.82
Isometric Bench Press (N kg^{-1})	6.67	0.74
Bench Press Power (W kg^{-1})	6.49	0.74
Bench Press Work (J kg^{-1})	26.50	0.76
Isometric Midthigh Pull (N kg^{-1})	18.53	0.85
Isometric Knee Extension (N kg^{-1})	5.54	0.82
Vertical Jump Power (W kg^{-1})	31.86	0.80
Wingate Power (W kg^{-1})	5.83	0.84
Aerobic Capacity (ml kg^{-1} min^{-1})	27.51	0.92