The Effect of Center of Gravity and Anthropometrics on Human Performance in Simulated Lunar Gravity

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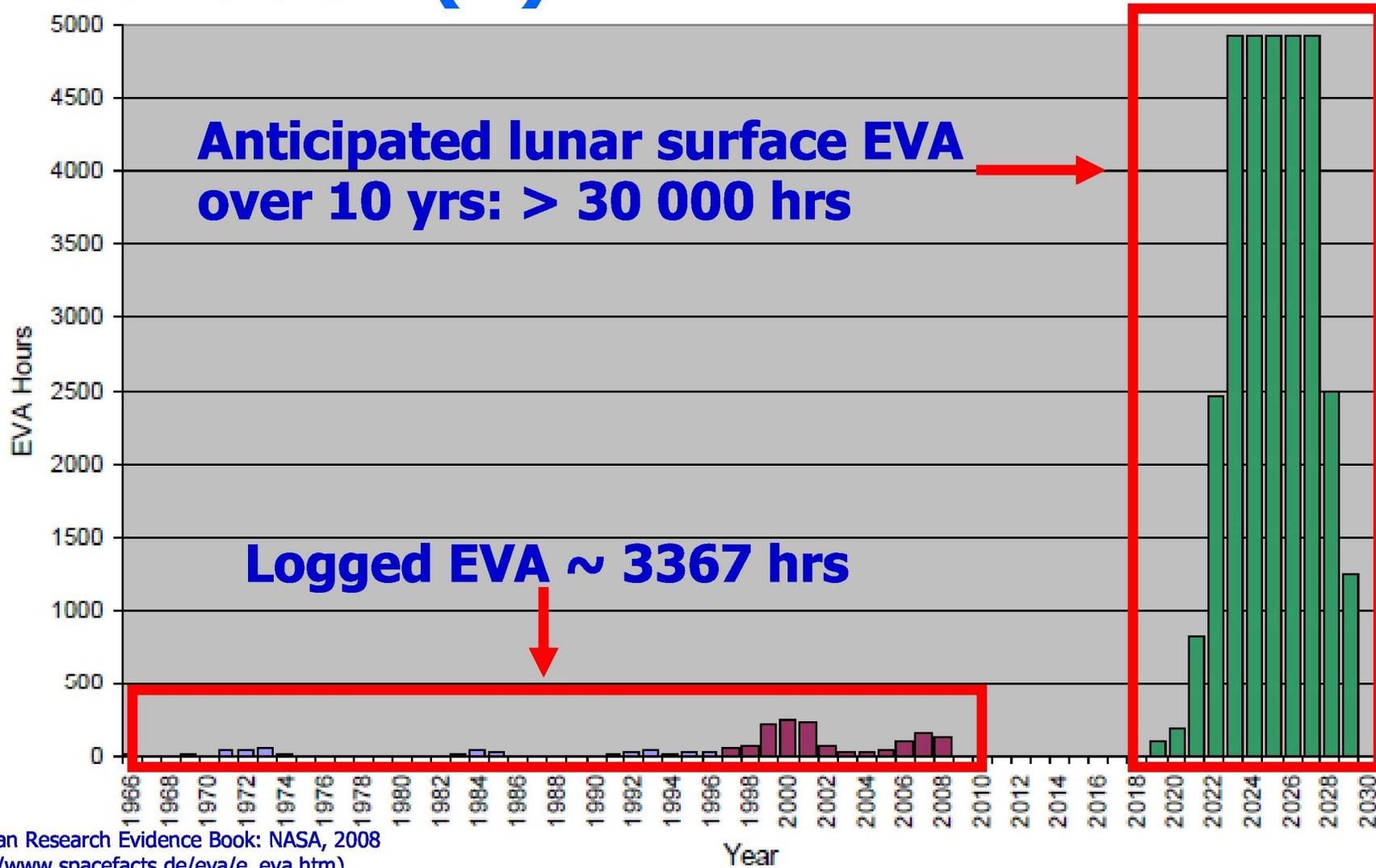Nicholas G. Skytland, Lyndon B. Johnson Space Center, NASA

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Presentation Outline

- Motivation
- Background
- Contribution
- Methods
- Results and Discussions
- Recommendations
- Conclusions

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Motivation (1)

- Revitalized interest to return to the Moon

- EVA hours to establish and operate a lunar base will greatly exceed all EVA hours logged since the beginning of human spaceflight

  - ESA HUMEX study: 960 hours for a single 180 day mission (Horneck and Comet, 2006)

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Motivation (2)

Anticipated lunar surface EVA over 10 yrs: > 30 000 hrs

Logged EVA ~ 3367 hrs

(Human Research Evidence Book: NASA, 2008
http://www.spacefacts.de/eva/e_eva.htm)

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Motivation (3)

- Tasks with highest potential to affect crewmember's safety and performance on the lunar surface are those that require EVA (ISU, 2008)

- Some Apollo mission objectives not fully met due to physical limitations the A7LB suits imposed on the crew

- Imperative to develop advanced spacesuits to allow astronauts to perform surface EVAs safely, efficiently, and effectively

- Major deficiency in Apollo suits believed to be instability caused by off-nominal CG induced by the PLSS

Motivation (4)
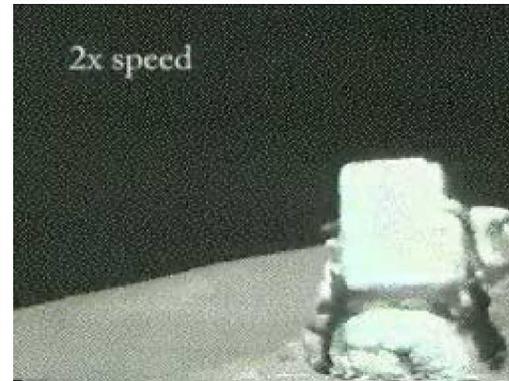
Background (1)

- NASA EVA Physiology, Systems and Performance (EPSP) Project at JSC has been investigating the effects of CG and other factors on astronaut performance in reduced gravity.

- A subset of the studies have been performed with the water immersion technique

(NASA)

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Background (2)

- Study results show correlation between CG location and performance

- However, data variability observed between subjects for prescribed CG configurations

- Hypothesis: Anthropometric differences between test subjects could be a source of the performance variability
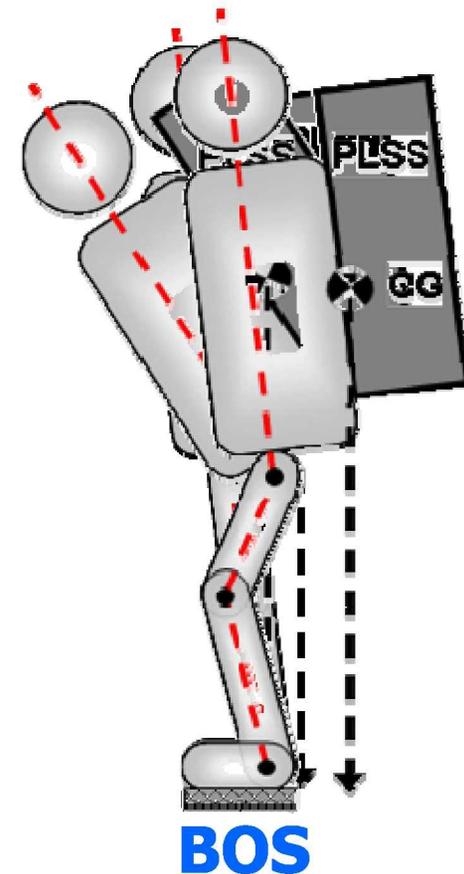
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Contribution (1)

(Mulugeta, 2008)

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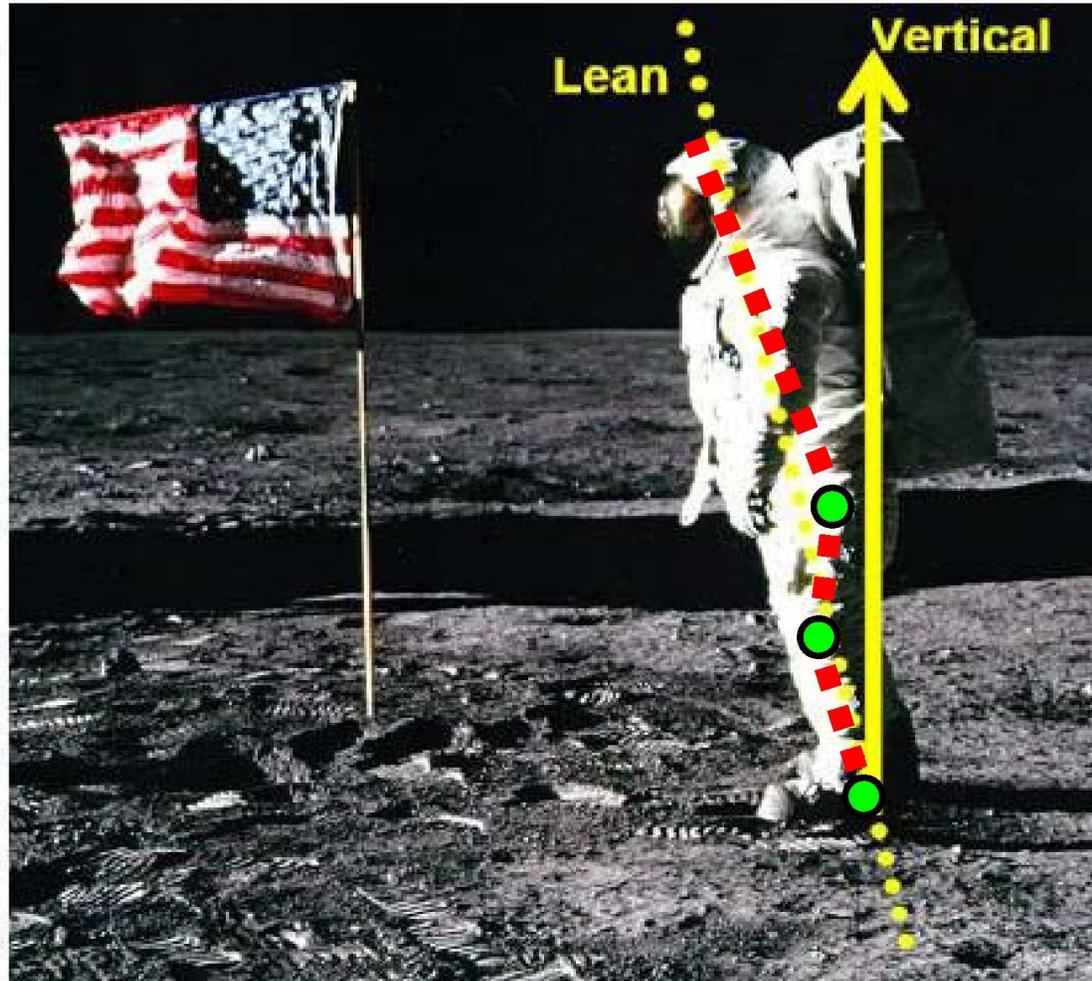
Contribution (2)

1. Lean via rotation about the ankle

2. Knee flexion, forcing CG farther AFT of the base of support (BOS) than would be achieved by pure lean via rotation about the ankle joint

3. Hip flexion for forward displacement of the CG over the BOS
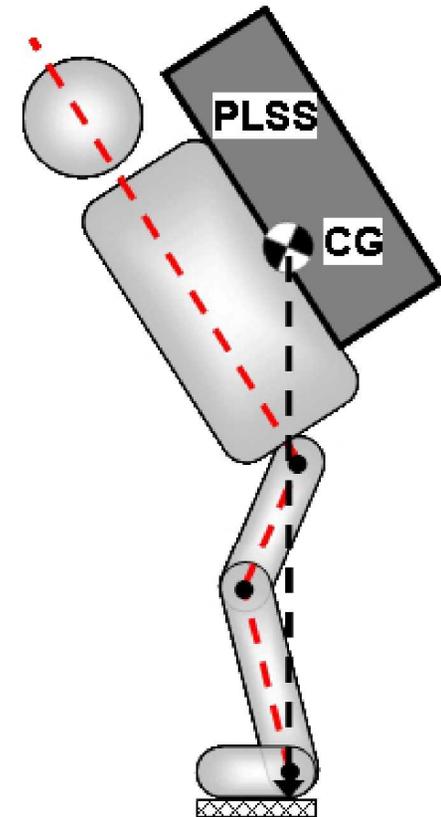

BOS

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Contribution (3)

$$THR = \frac{Trunk}{Height}$$

↑**THR** ↑**Performance**

$$TSR = \frac{Thigh}{Shank}$$

↓**TSR** ↑**Performance**

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Contribution (4): Illustrated example

High THR (THR = 0.364)   **Low THR (THR = 0.297)**

PLSS · CG · 68.6 cm · 163.5° · θ=7.5°

PLSS · CG · 57.2 cm · 158.5° · θ=7.5° · 182.9 cm (6 ft) · H_{CG}

Note more acute hip angle for Low THR

CG Compensation   Upright Position   CG Compensation   Upright Position
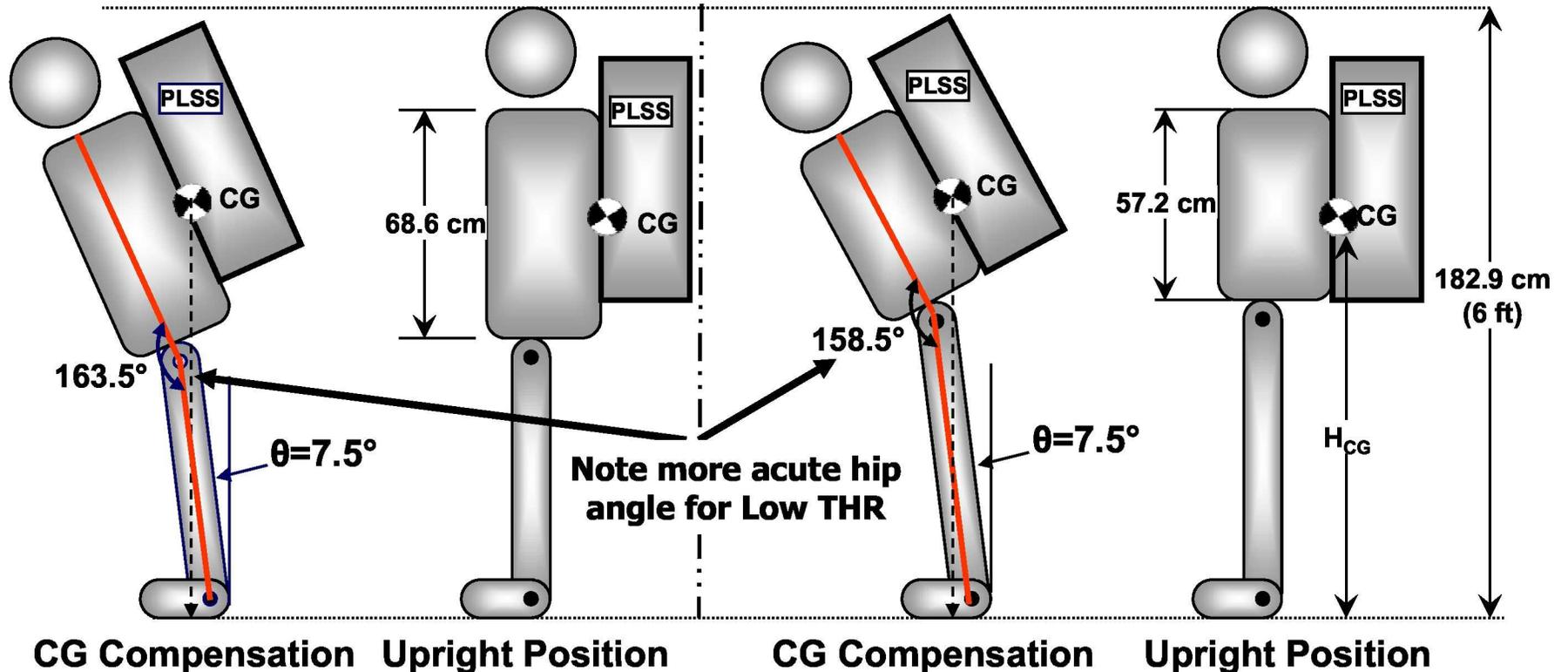
Assumptions of illustrative example

- θ = 7.5° from direct measurements of figure on slide 9 (Buzz saluting flag)
- Both subjects are the same height
- Knee bend ignored (future studies)
- CG location the same for both subjects (H_{CG})

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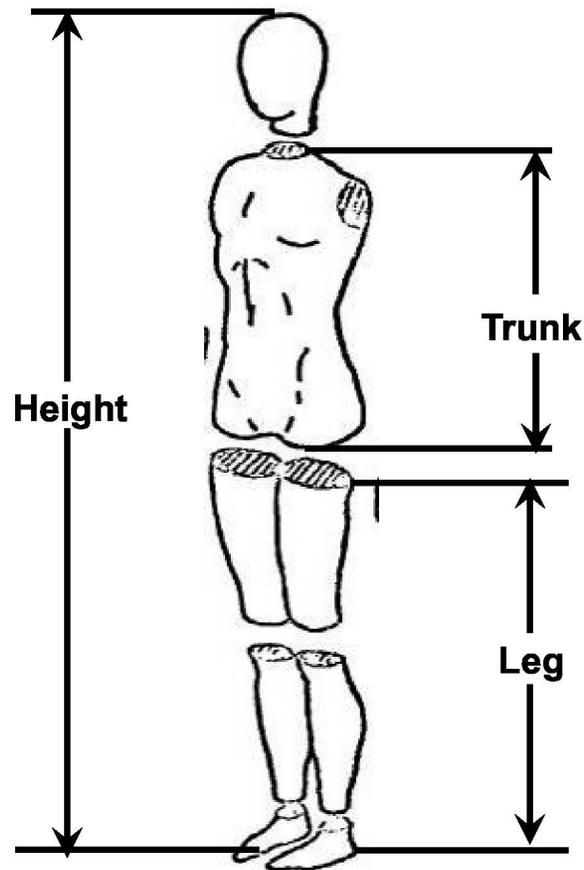# Methods: Anthropometrics & Subjects

Parameter	Mean	± SD	Range	Test Environment
Mass (kg)	73.1	13.9	46.9 - 95.3	NBL + NEEMO
Height (cm)	177.2	7.4	159.5 - 187.1	
Trunk (cm)	72.0	3.8	65.7 - 77.6	
THR	0.406	0.010	0.391 - 0.423	
Mass (kg)	70.4	14.4	46.9 - 83.5	NBL
Height (cm)	178.6	8.9	159.5 - 187.1	
Trunk (cm)	72.5	4.3	65.7 - 77.8	
THR	0.406	0.012	0.391 - 0.421	
Mass (kg)	75.5	13.8	56.7 - 95.3	NEEMO
Height (cm)	176.0	6.1	167.5 - 183.6	
Trunk (cm)	71.6	3.6	67.9 - 77.6	
THR	0.406	0.009	0.398 - 0.423	

Environment	No. of Subjects
NBL	8
NEEMO	9
Total	17

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Methods: Tasks

No.	Task	Task Description	NBL	NEEMO
1	Preferred Ambulation	Ambulate as desired	Y	Y
2	Fall-Recovery	Fall forward and get up	Y	Y
3	Shoveling	Scoop a pile of gravel/sand with shovel	Y	Y
4	Rock Lift	Pick up rock from ground with one hand	Y	Y
5	Kneel-Recovery	Fall to one knee and get up	Y	Y
6	Timed Walk	Walk 9 m with one foot always on ground	Y	Y
7	Timed Jog	Traverse 9 m at slowest speed which both feet leave ground	Y	Y
8	Timed Run	Traverse 9 m at fastest speed	N	Y
9	Ladder Climb	Climb ladder	Y	Y
10	Jumping	Jump standing in place	Y	N
11	Rock Task	Transport rock between 2 locations	Y	N
12/13	Ramp +/-10º	Walk up/down 10º slope	Y	N
14/15	Ramp +/-15º	Walk up/down 15º slope	Y	N
16/17	Ramp +/-20º	Walk up/down 20º slope	Y	N
18/19	Ramp +/-25º	Walk up/down 25º slope	Y	N
20/21	Ramp +/-30º	Walk up/down 30º slope	Y	N

Methods: CG Adjustment (1)

CG Configuration Designation	X (cm)	Z (cm)
△ Ideal	-0.08	4.1
◆ Baseline	-7.6	14.4
□ High	0.08	26.5
○ Low	-0.08	-6.6
● Aft	-15.0	-0.16
■ Forward	0.33	-0.05
◆ Apollo	-9.3	11.9
○ 0,0,0	0	0

Methods: CG Adjustment (2)

Cantilevered weights on adjustable rails

Clearance for air hoses

Adjustable Shoulder strap attachment points

Padding Adjustable to any position

Quick Release Straps
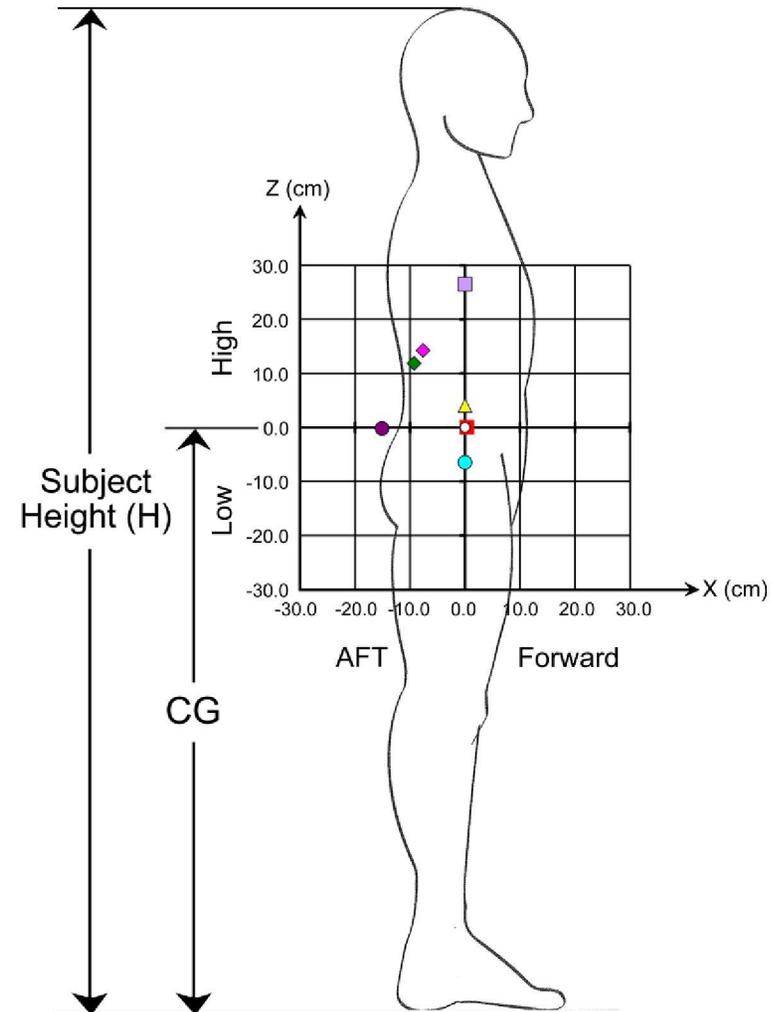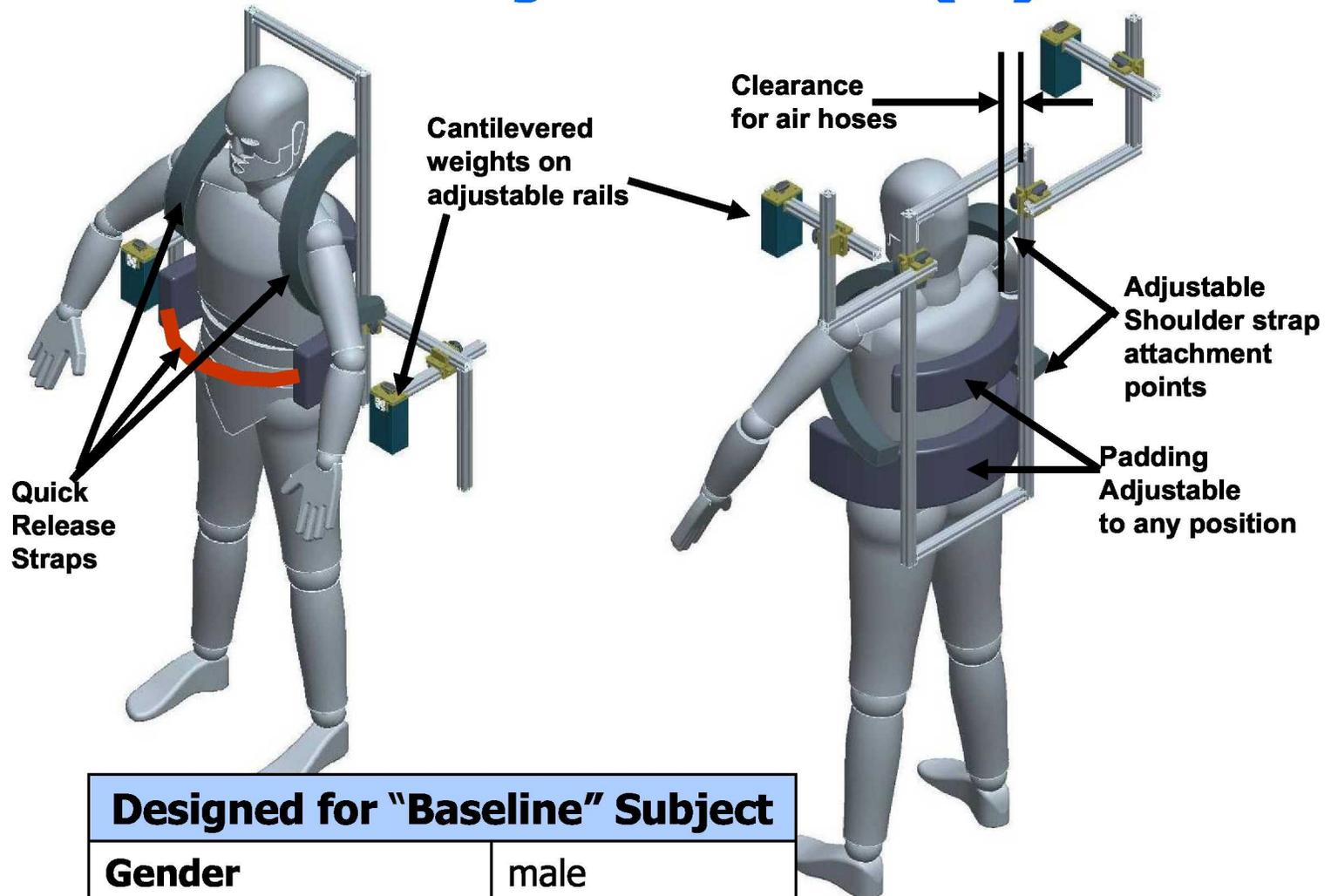
Designed for "Baseline" Subject	
Gender	male
Mass/weight (kg)	81.8 (180 lb)
Height (cm)	182.9 (6 ft)

(NASA)

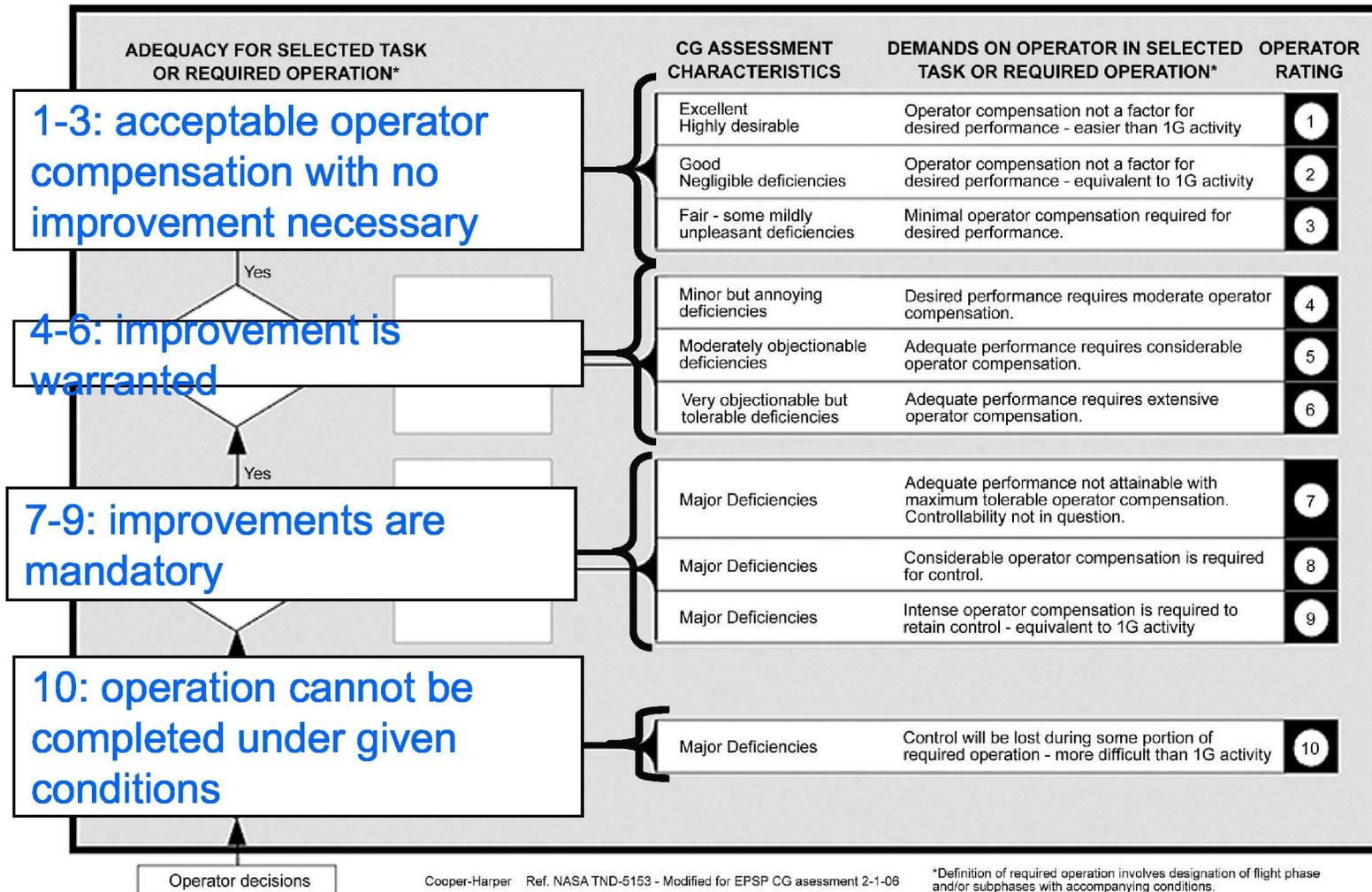2009-01-2561

Methods: Test Facilities

Methods: Data Acquisition (1)

- Subjective performance data collected using a modified Cooper-Harper (CH) Rating Scale

- Derived from the Cooper-Harper Pilot Rating Scale (CHPRS) for aircraft handling performance

- Flight experienced test subjects required for CHPRS and for any adaptations of CHPRS

- Since EPSP test subjects did not have lunar EVA experience, the modified CH scale employs 1-g shirtsleeve operation as a baseline reference for performance rating

- 1-g reference effectively qualifies subjects as experienced operators

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Methods: Data Acquisition (2)

MODIFIED COOPER-HARPER RATING SCALE

1-3: acceptable operator compensation with no improvement necessary

4-6: improvement is warranted

7-9: improvements are mandatory

10: operation cannot be completed under given conditions

ADEQUACY FOR SELECTED TASK OR REQUIRED OPERATION*	CG ASSESSMENT CHARACTERISTICS	DEMANDS ON OPERATOR IN SELECTED TASK OR REQUIRED OPERATION*	OPERATOR RATING
	Excellent Highly desirable	Operator compensation not a factor for desired performance - easier than 1G activity	1
	Good Negligible deficiencies	Operator compensation not a factor for desired performance - equivalent to 1G activity	2
	Fair - some mildly unpleasant deficiencies	Minimal operator compensation required for desired performance.	3
Yes	Minor but annoying deficiencies	Desired performance requires moderate operator compensation.	4
	Moderately objectionable deficiencies	Adequate performance requires considerable operator compensation.	5
	Very objectionable but tolerable deficiencies	Adequate performance requires extensive operator compensation.	6
Yes	Major Deficiencies	Adequate performance not attainable with maximum tolerable operator compensation. Controllability not in question.	7
	Major Deficiencies	Considerable operator compensation is required for control.	8
	Major Deficiencies	Intense operator compensation is required to retain control - equivalent to 1G activity	9
	Major Deficiencies	Control will be lost during some portion of required operation - more difficult than 1G activity	10

Operator decisions

Cooper-Harper   Ref. NASA TND-5153 - Modified for EPSP CG asessment 2-1-06   *Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

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Methods: Analysis (1)

- For each task performed, linear regressions were generated using MS Excel 2003
  - CH vs. Trunk-to-Height Ratio (THR)
  - CH vs. Height
  - CH vs. Trunk Length
  - CH vs. Body Mass/Weight

- 936 regressions generated

- Primary purpose of this analysis was to guide future detailed logistic regression analyses of potential anthropometric factors that may affect performance in reduced gravity

Methods: Analysis (2)

- Regressions interpreted strictly for slope (positive or negative)

- Magnitude of slope not considered

- Avoids subjective interpretation of results based on subjective data

Results & Discussions: CH vs. THR (1)

- The CH vs. THR results supported the hypothesized direct relationship between performance and THR
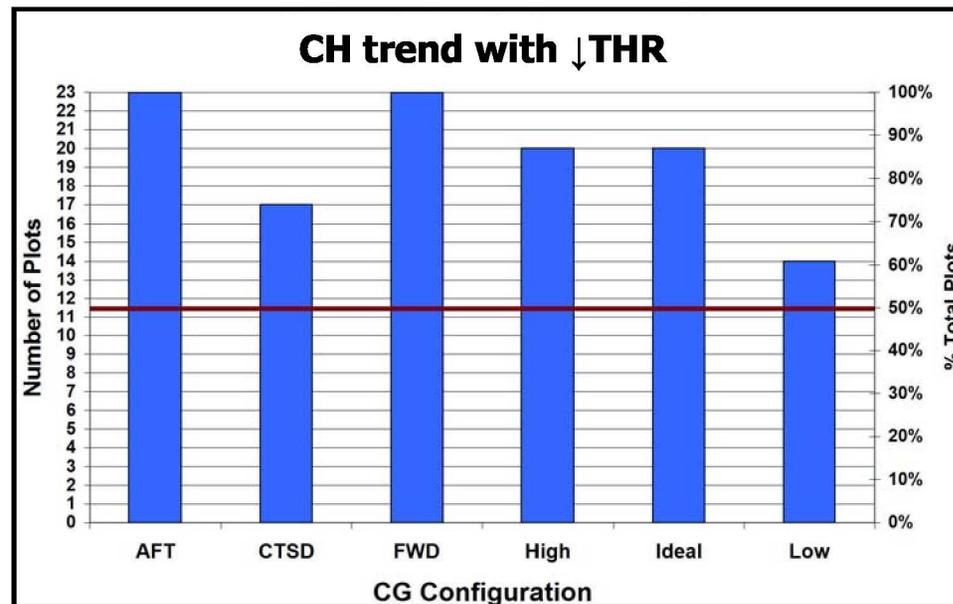
- 116 out of 138 regressions (84%) showed increased CH rating with decreased THR (↑CH = decreased performance)

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Results & Discussions: CH vs. THR (2)

- The subject with the <u>lowest</u> THR gave the <u>highest</u> CH rating for all tests (lowest performance)

- The test subject with the <u>highest</u> THR gave the <u>lowest</u> CH ratings for 17 out of the 21 tasks performed (best performance)

- Gervais and Moreau (2001) showed that higher performing marathon runners tend to run with more upright posture, and lower performing runners tend to run with a more forward trunk lean

- BWSS Martian gravity tests by Scott-Pandorf (2008) showed reduced forward lean increases back comfort and reduces energy expenditure

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Results & Discussions: CH vs. THR (3)

- Lucia *et al.* (2006) compared running economy of Eritrean runners (N=7) and Spanish runners (N=9) with respect to training regime, anthropometrics and running strategy

- Eritreans' training experience, training volume, and VO_2 cost of running were significantly lower

- Superior performance may, at least partly, be associated with their anthropometrics

- Lucia *et al.* found that Eritrean runners had lower body mass index and limb mass

- Further evaluation of the Lucia *et al.*'s anthropometric data was carried out in this study with regard to THR and TSR

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Results & Discussions: CH vs. THR (4)

- Since Lucia *et al.* did not present the mean trunk length of the runners, upper-body to height ratio (UHR) was used in the analysis

$$UHR = \frac{Height - Leg\ Length}{Height}$$

- UHR assumed to have the same effect as THR since the trunk accounts for most of the upper-body mass and MOI

- Limited martian gravity performance data also showed direct correlation between UHR and performance (Mulugeta, 2008)

Results & Discussions: CH vs. THR (5)

- Mean TSR of the two groups also compared to test hypothesized inverse relationship of TSR and performance

$$TSR = \frac{Thigh}{Shank}$$

- Result: Eritreans had <u>higher UHR</u>, and <u>lower TSR</u> than Spaniard runners
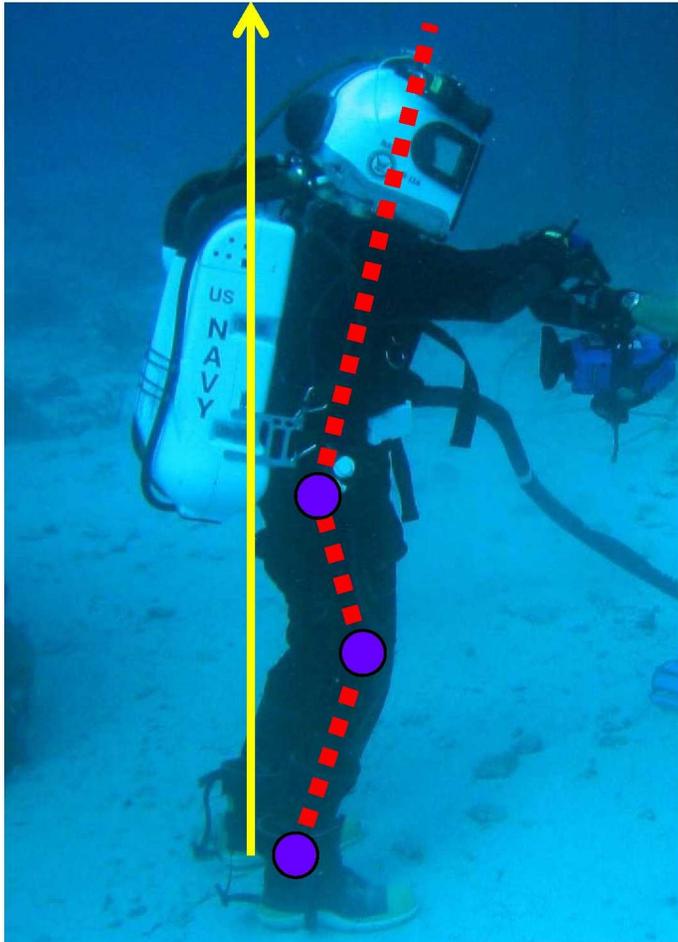
Anthropometric Parameters	Mean ± SD	
	Eritreans	Spaniards
Leg Length (cm)	92.3 ± 6.5	92.6 ± 3.6
Height (cm)	174 ± 8	172 ± 6
Height-Leg (cm)	81.7 ± 10	79.4 ± 7
Thigh Length (cm)	48.2 ± 4	51.9 ± 3.6
Shank Length (cm)	44.1 ± 3	40.6 ± 2.7
UHR	0.470 ± 0.06	0.462 ± 0.04
TSR	1.093 ± 0.01	1.278 ± 0.12

Results & Discussions: CH vs. THR (6)

- Ward *et al.* (1979) evaluated impact of anthropometrics on performance of master and first class Olympic weight lifters trained for the clean and jerk, and the snatch lifts

- Ward *et al.* noted Master lifters exhibited greater mass lifting performance and higher THR

- Further assessment of the anthro. presented by Ward *et al.* also showed the master lifters had lower TSR

Anthropometric Parameters	Mean $\pm$ SD	
	Master (N=7)	First Class (N=7)
Trunk Length (cm)	59.4 $\pm$ 1.9	56.4 $\pm$ 2.2
Height (cm)	172.6 $\pm$ 1.8	172.8 $\pm$ 7.7
Thigh Length (cm)	36.1 $\pm$ 3.7	39.3 $\pm$ 3
Shank Length (cm)	36.1 $\pm$ 1.8	36.8 $\pm$ 2.2
THR	0.344 $\pm$ 0.012	0.326 $\pm$ 0.019
TSR	1.00 $\pm$ 0.11	1.07 $\pm$ 0.10

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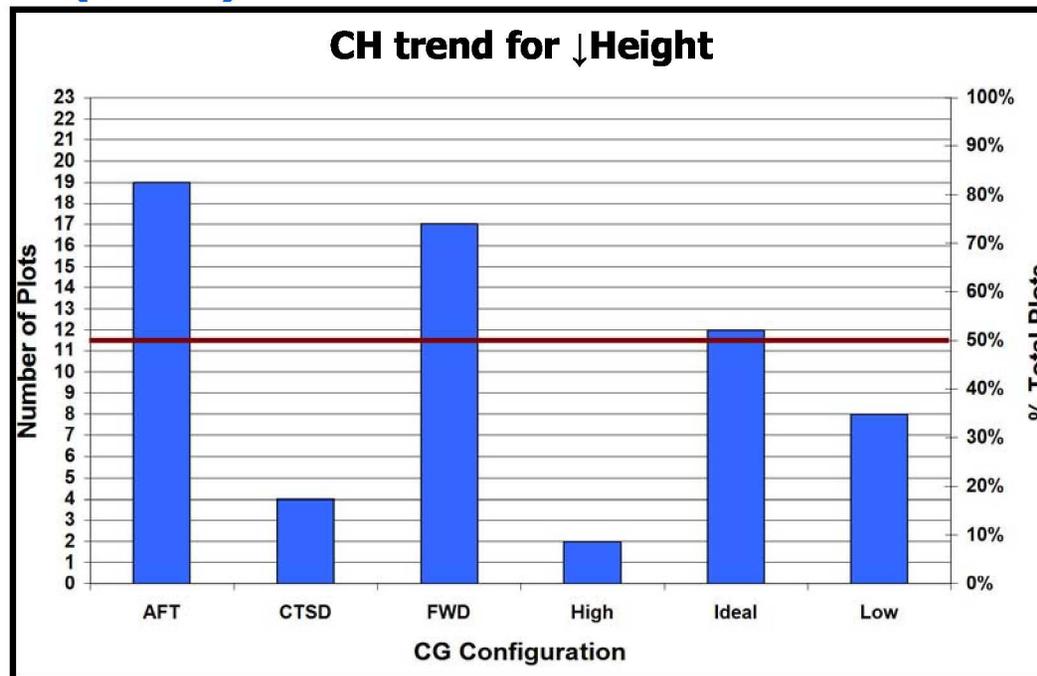# Results & Discussions: CH vs. THR (8)

1. Lean via forward rotation about the ankle

2. Knee flexion

3. Forward waist flexion

Representative NEEMO photographs support the CG compensation mechanisms suggested

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Results & Discussions: CH vs. Height

- CH against Height showed both direct and inverse correlations (50%)

CH trend for ↓Height

- Height of the subjects with the highest and lowest THR were within 2 cm of the average height, implying that height has less influence on performance than THR
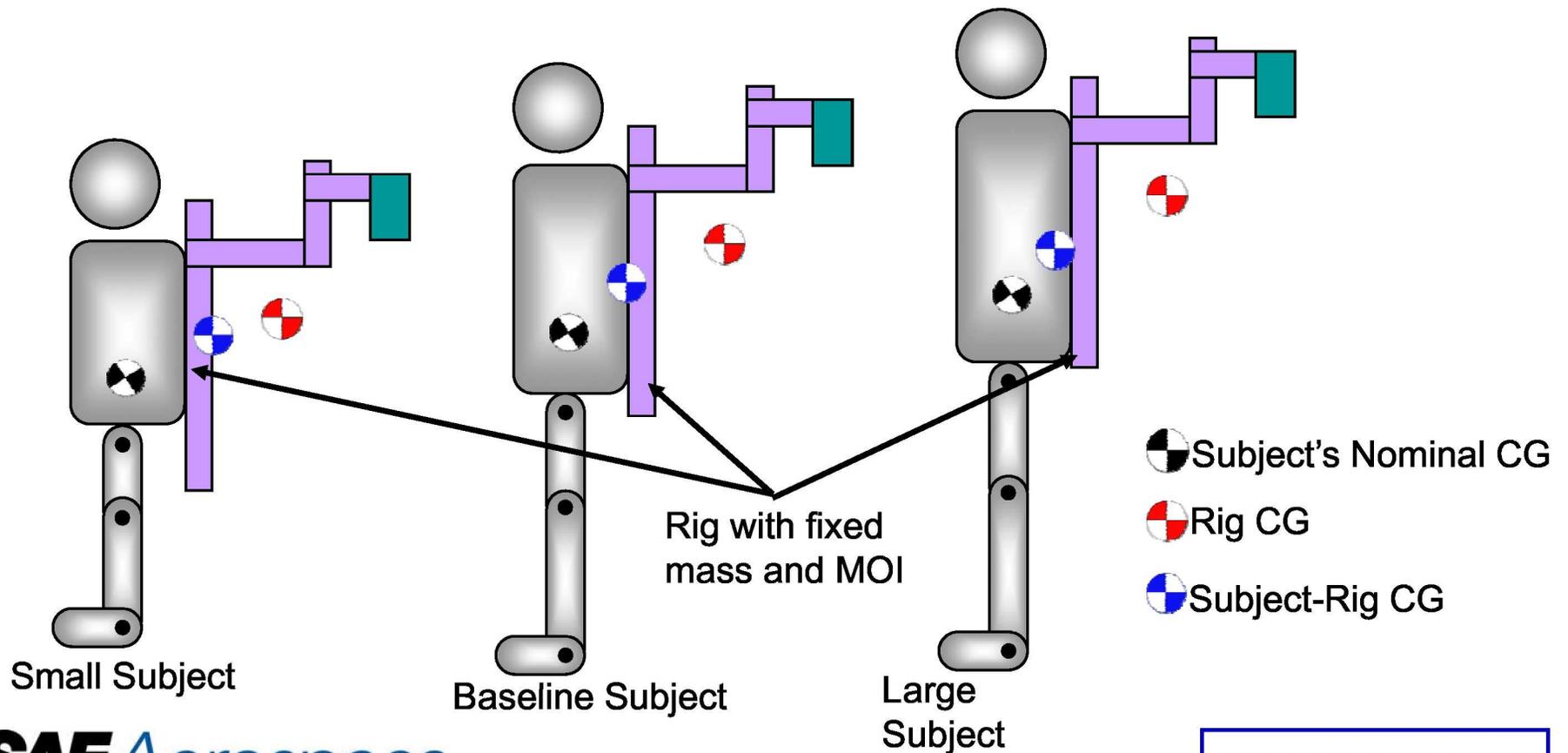
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Results & Discussions: CH vs. Trunk Length (1)

- Similar to CH vs. Height regressions, CH vs. trunk length regressions also showed both direct and inverse correlations

CH trend for ↓Trunk Length
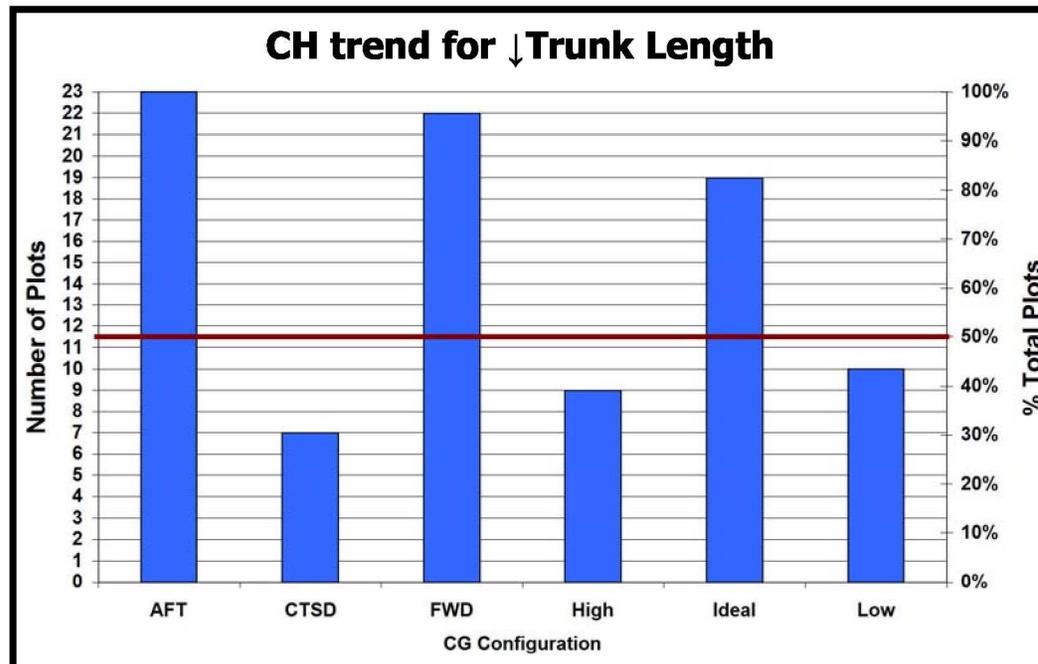
- However, results suggest trunk length may have greater influence on performance than height

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Results & Discussions: CH vs. Trunk Length (2)

- The greater influence of trunk length on performance may be related to the relative differences in upper-body mass and MOI between the subjects with respect to the CG rig

Small Subject

Baseline Subject

Large Subject

Rig with fixed mass and MOI

Subject's Nominal CG

Rig CG

Subject-Rig CG

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Results & Discussions: CH vs. Body Mass

- For CH vs. body mass/weight plots, 4 of the 6 CG configurations showed an increase in CH with decreased mass/weight

CH trend for ↓Body Mass/Weight
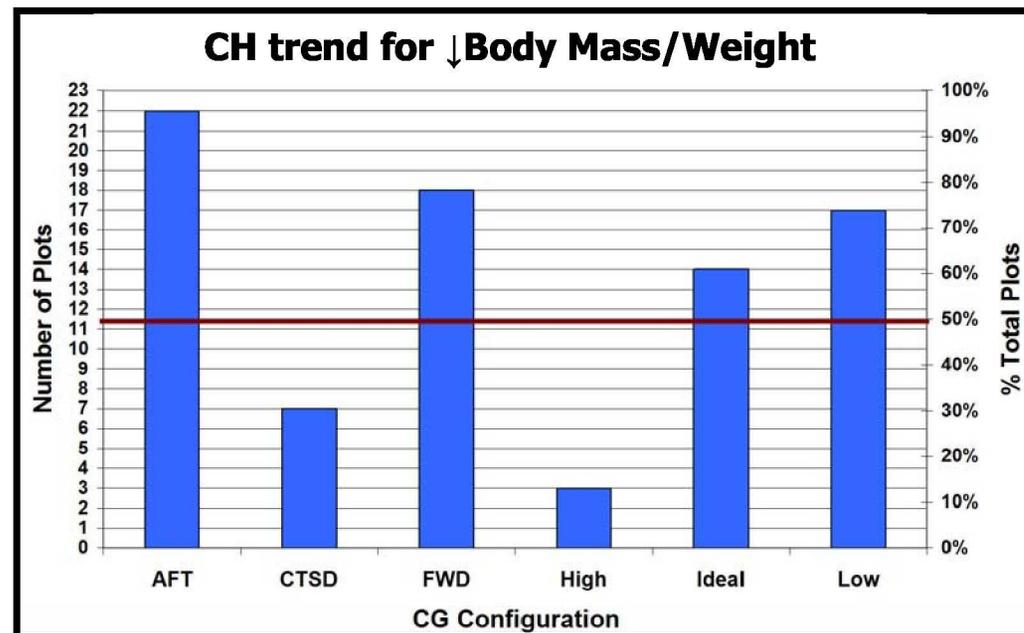
- Preliminary work by EPSP showed increased performance with increase suit weight in BWSS simulated lunar-g

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Recommendations (1)

- Validation of the EPSP "modified" CH scale by:
  - Incorporating a non-subjective performance measurement system (e.g. metabolic rate measurement) or
  - Subjective RPE (rating of perceived exertion) whenever direct metabolic measurement is not possible

- Analysis of CH data to verify the relationship between TSR and performance

- Assess the influence of standardized CG rig or PLSS design for a baseline subject (182.9-cm and 81.8-kg male) can affect performance of subjects with varying anthropometrics
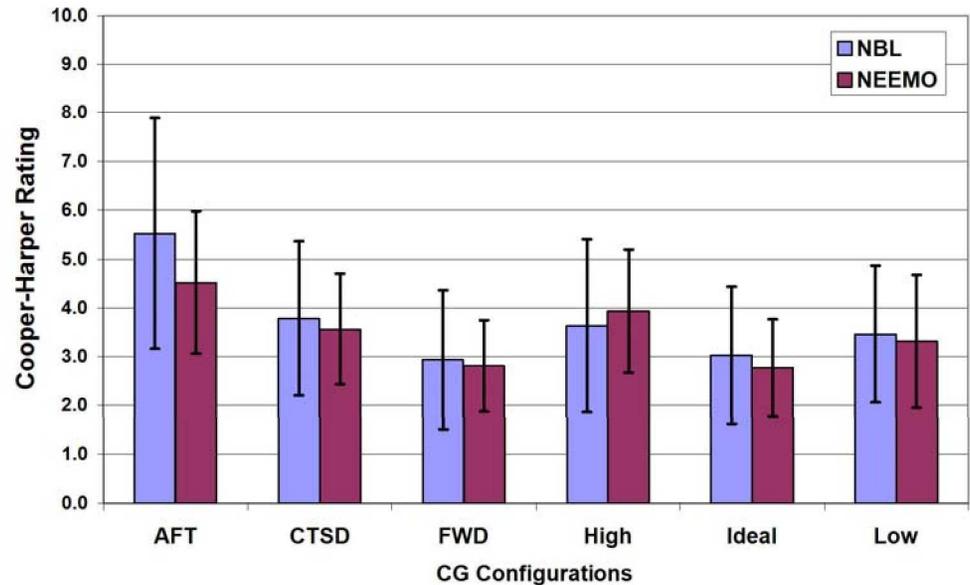
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Recommendations (2)

- Measures should be taken to account for changes in environmental and operational conditions per CHPRS guidelines

NBL and NEEMO regression comparison

R² NBL = 0.4375
R² NEEMO = 0.183
R² Total = 0.2703
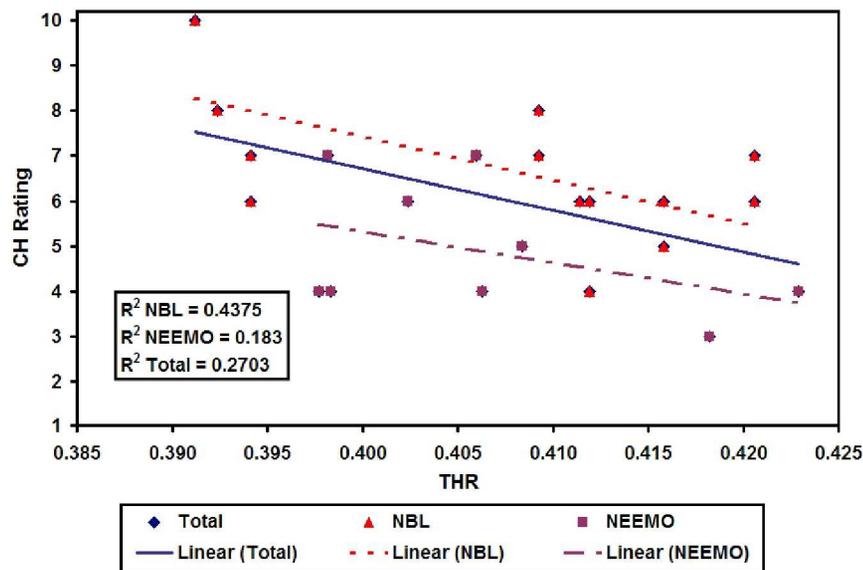
Comparison of NEEMO and NBL Mean CH

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Recommendations (3)

- When developing performance predictive regression models at the next phase of this work
  - THR should be considered a main parameter and
  - Body mass as a possible secondary parameter

- Further testing should be performed in prototype lunar exploration suits

- Suited test data and unsuited results, should be useful for future spacesuit design for optimum astronaut performance and safety

Conclusions (1)

- Results support the hypotheses stated regarding the:
  - Three mechanisms of CG offset compensation and
  - Direct relationship between THR and human performance in simulated reduced gravity

Anthropometric Parameter	Dominant CH Trend
↓ THR	↑CH
↓ Height	↔CH
↓ Trunk Length	↔CH
↓ Body Mass	↑CH

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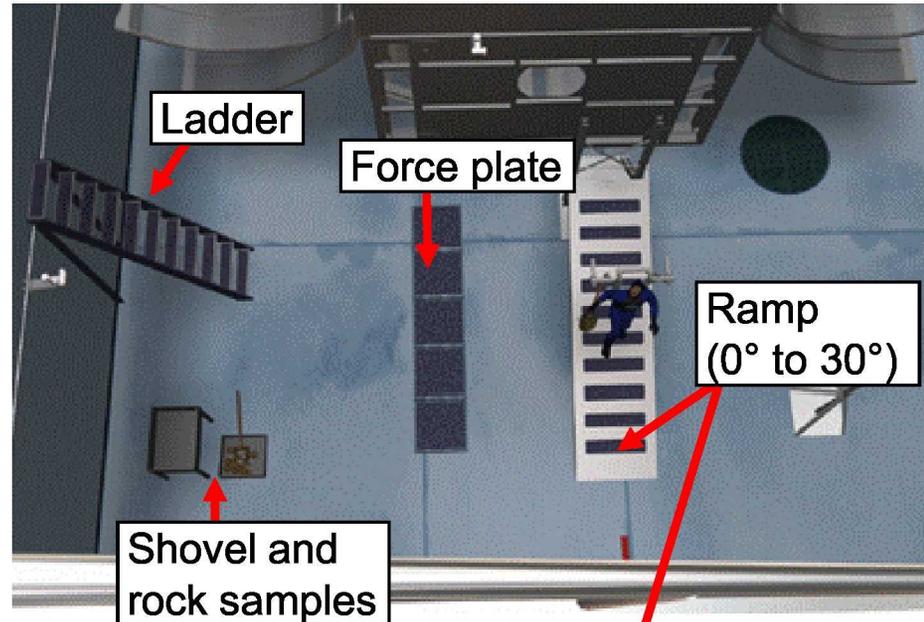An SAE International Group

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Conclusions (2)

- Literature presented to support the hypothesized inverse relationship between TSR and performance

- Results suggest some correlation between body mass and performance in simulated lunar-g

- Results to be used in future detailed logistic regression analysis of potential anthropometric factors that:
  - may influence human performance in reduced gravity and
  - drive future spacesuit design

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Questions?

Backup Slides

Methods: NBL Tests

Ladder

Force plate

Ramp
(0° to 30°)

Shovel and
rock samples

Performing
task while
standing
on force
plate

(NASA)

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Methods: NEEMO tests

NEEMO tests performed using both specifically designed test equipment and preexisting structures near the NEEMO habitat

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Results & Discussions: CH vs. THR

- Ward *et al.* suggested shorter legs allowed the master lifters to keep the weight closer to the body midline and to have less distance to move and get under the weight

- Further assessment of the anthropometrics presented by Ward *et al.* also showed the master lifters had lower TSR than the first class lifters

Anthropometric Parameters	Mean $\pm$ SD	
	Master (N=7)	First Class (N=7)
Trunk Length (cm)	59.4 $\pm$ 1.9	56.4 $\pm$ 2.2
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