Neutral Body Posture in Spaceflight

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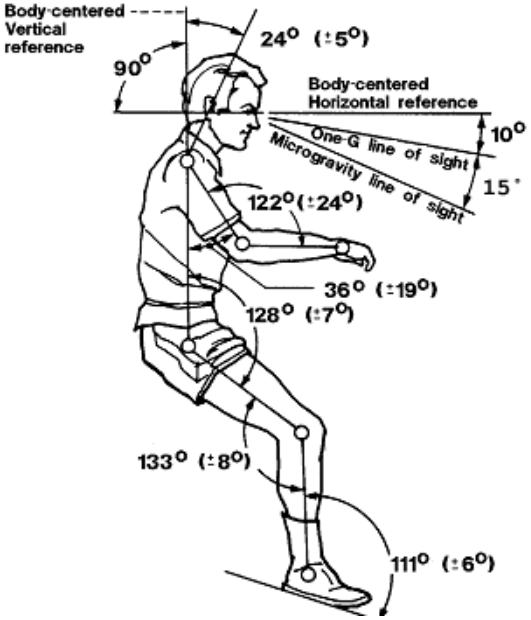
Neutral Body Posture (NBP): Definition and Significance

- Human body in 0-g exhibits a unique posture (neutral body posture; NBP), when relaxed and no external forces are applied
- The early designs for spaceflight hardware were based on upright standing or sitting postures without consideration of NBP, resulting in crew discomfort. Maintaining a body posture other than NBP requires significant strength exertions
- NBP has been adopted for newer system designs, including the computer consoles and space suits. NASA Human Factors and Health Technical Standards (NASA STD-3000) specifies NBP as a reference posture

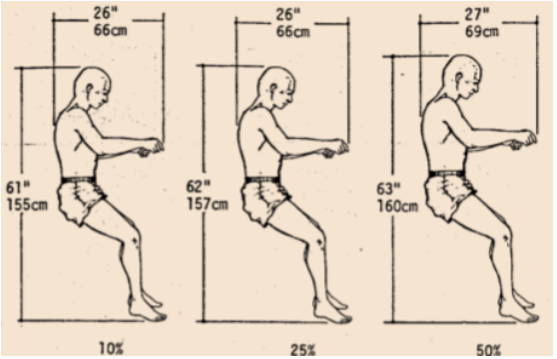
Similar underwater postures (Dirlich, 2010; Akin 2014)



NASA STD-3000

Measurements of NBP: Past Work and Potential Issues

- Previous work to measure NBP:
  - Skylab-4 (1975): outline tracking from frontal and side view photograph
  - Shuttle STS-57 (2003): multi-view photographs and anthropometric CAD



- Difficulties with photograph-based NBP measurements:
  - Optical distortions from uncalibrated photogrammetry (1)
  - Unidentified camera position and view angle (2)
  - Scale mismatch from unknown anthropometry and body shape (3)

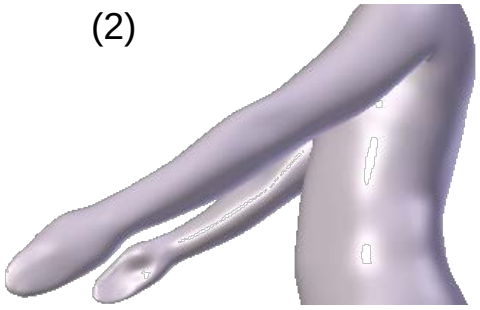
Same Posture Resulting in Different Views (Simulations)

View through 200 mm lens

(1)

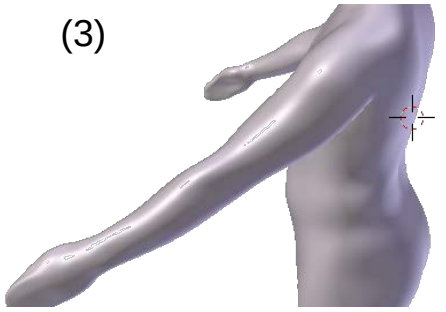
18 mm lens view

(2)



Camera moved down

(3)



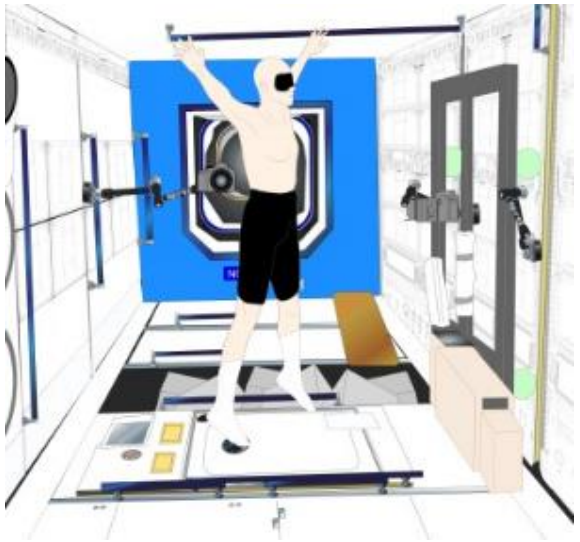
Arms artificially rescaled

Goal and Methods

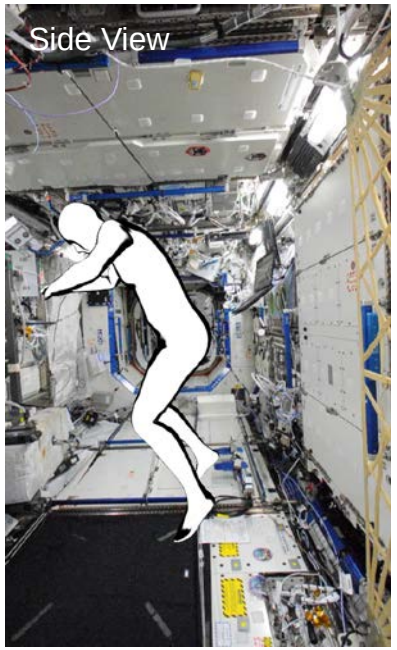
- Goal: define a structured methodology to estimate the NBP
- 9 International Space Station (ISS) crewmembers participated
  - 3 subjects were analyzed for this study
- The subjects wore individually fit spandex and eye mask
- Two cameras (one front and one side) recorded video images
- Prior to NBP, the subject performed a set of randomly ordered effort cycles
  - 5-10 seconds of crouch or stretch
  - 60 seconds of relaxation and neutral phase

Crouch

Stretch

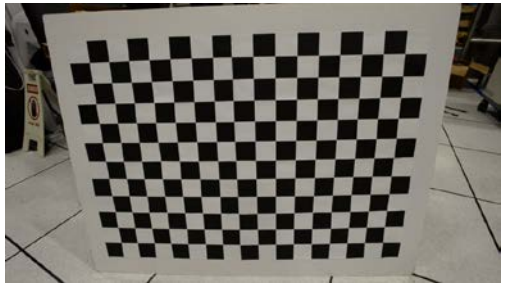


Images downloaded from ISS
(body silhouetted for anonymization)

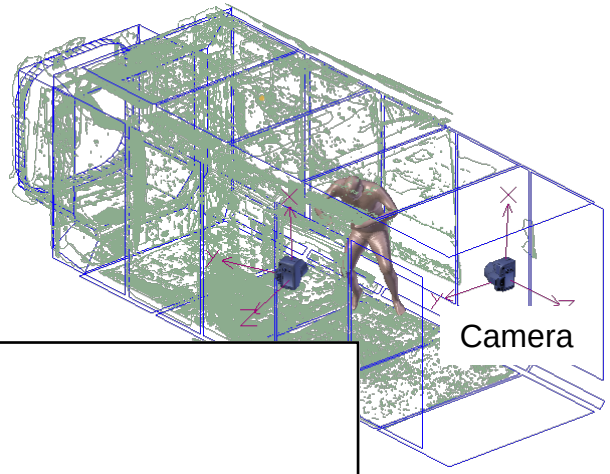


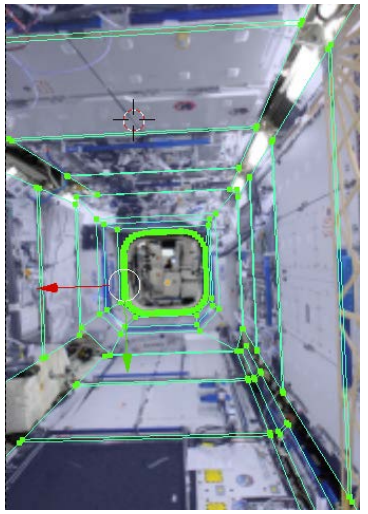
New Technique for 3D Photogrammetry

- Calibrated cameras using checkboard images
  - Estimate camera parameter matrix (e.g., focal length, skew, distortion, image center)
  - Reduce optical distortions on images

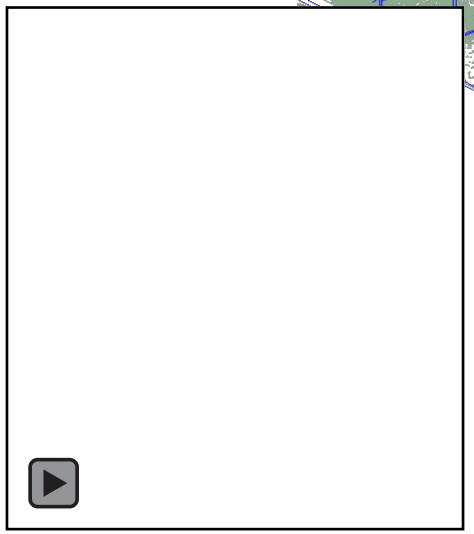


- Estimated camera position and orientation:
  - 3-D scanned the ISS mockup interior
  - Matched the feature point coordinates between the images and 3D scans
  - Estimated the optimal camera position minimizing reprojection error



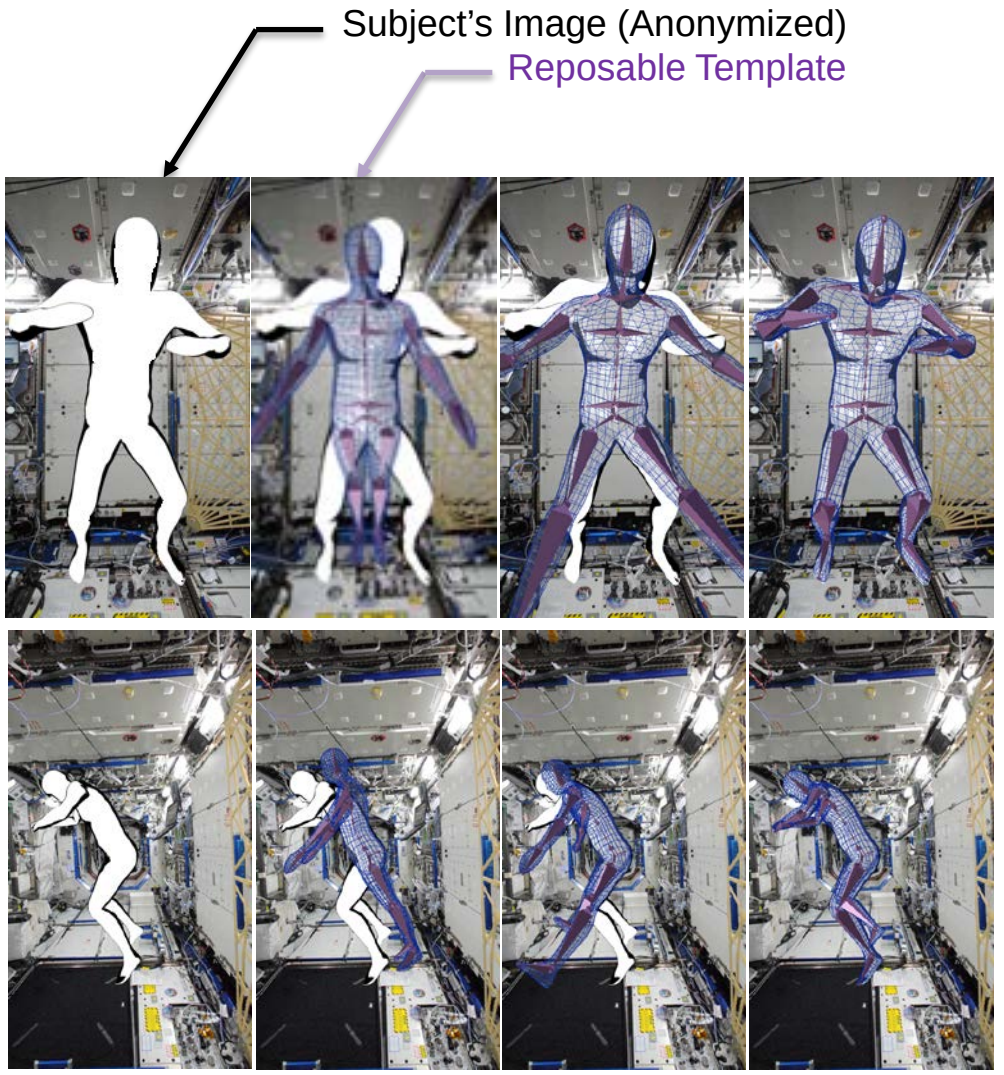


- Generated individual body templates from 3D scans
  - Reduced error from the mismatching body shapes and segment dimensions
  - Skeletal link system was embedded for reposing



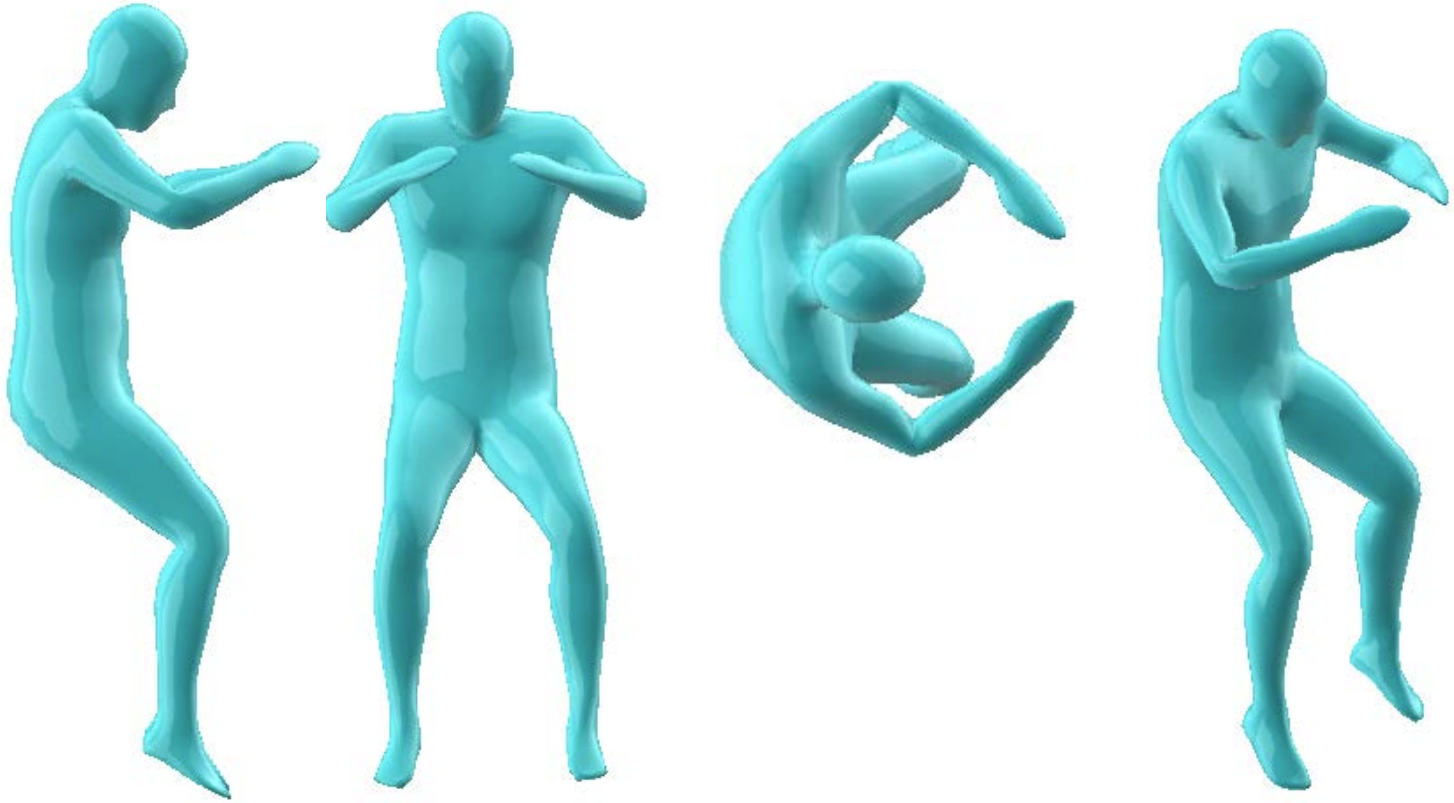
3D Posture Estimation

- The 3D template manikin was placed within the ISS mockup scan geometry
- The manikins were projected onto the virtual cameras and overlaid on the subjects' images
- The manikin was manually translated and rotated to align the projected torso with the subjects' images
- The skeletal joints were manually articulated until the overlap is maximized between the body segment projection and the corresponding subject image body part
- The alignment and articulation steps were repeated to refine the posture

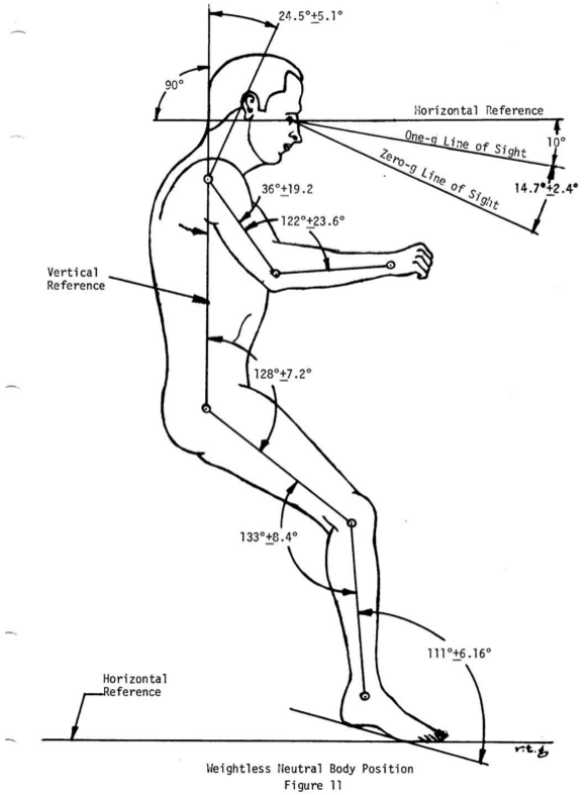


NBP Estimated from New Methodology

- The extracted postures show overall consistency with historical NBP measurements, characterized by the semi-crouched torso, flexed arms and legs, and forward bent head and neck
- Unlike the previous studies, the new methodology can better represent NBP using a 3D body manikin with the matching anthropometry and body shape



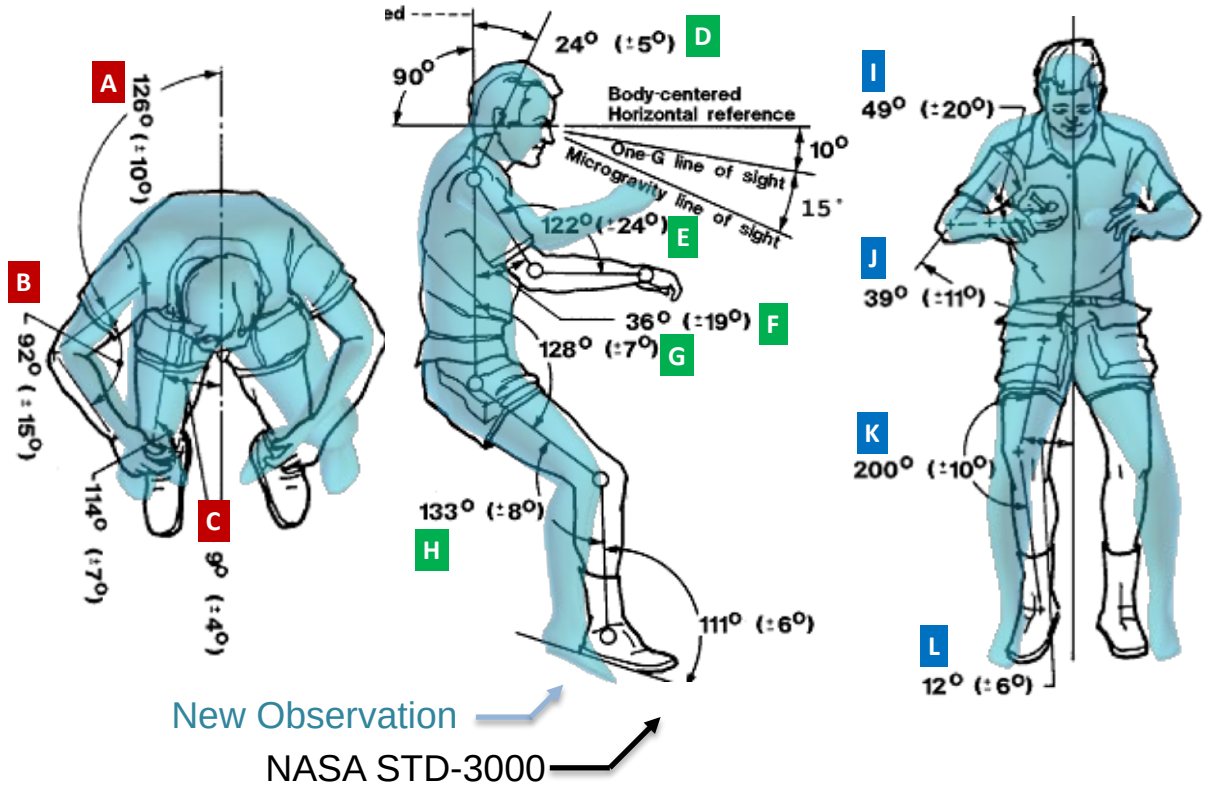
Average Geometry and Posture Angle from Analyzed Subjects



Skylab-4 Measurements (1975)

New Posture Angles Compared to NASA Standard

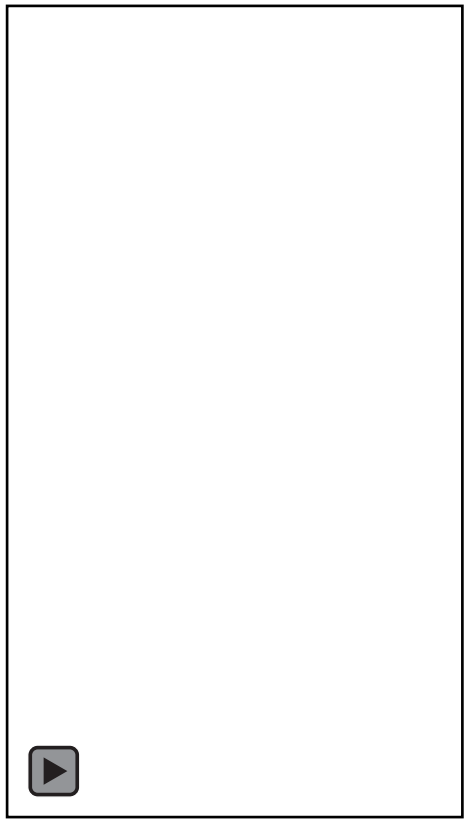
- Despite the overall similarity, 7 out of 12 angle types are statistically different from NASA STD-3000
- Significant differences are primarily observed from upper and lower extremity angles



Angle Label	New Observations Mean	Bootstrap 99% Confidence Interval		NASA STD-3000	$p < 0.01$
A	130	[125,	136]	126	
B	103	[95,	112]	92	**
C	22	[18,	27]	9	**
D	28	[24,	33]	24	**
E	122	[113,	130]	122	
F	39	[36,	43]	36	**
G	135	[129,	142]	128	**
H	125	[116,	134]	133	
I	57	[50,	63]	49	**
J	35	[32,	39]	39	
K	197	[192,	201]	200	
L	16	[13,	18]	12	**

Trial-to-Trial Posture Variations

- Postures vary across the replicated trials, especially in extremity angles
- However, posture angles do not consistently vary with the preceding effort type. The crouch versus stretch conditions do not have statistically significant influences on the NBP

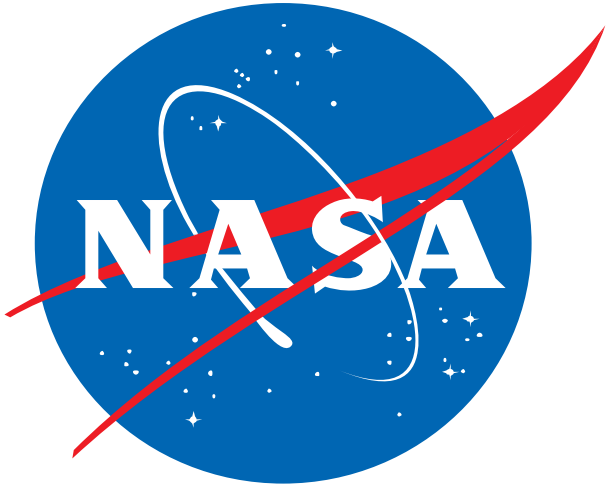


Angle Label	After Crouch		After Stretch		$p<0.01$
	Mean	Bootstrap 99% Confidence Interval	Mean	Bootstrap 99% Confidence Interval	
A	127	[122, 134]	133.9	[126, 141]	
B	101	[91, 118]	105	[94, 114]	
C	21	[18, 25]	23.6	[15, 32]	
D	31	[23, 38]	26.2	[25, 27]	
E	120	[109, 133]	123.9	[113, 134]	
F	39	[35, 46]	39.9	[36, 43]	
G	133	[128, 138]	137.6	[127, 148]	
H	123	[116, 129]	127.5	[112,142]	
I	54	[46, 64]	60.5	[51, 66]	
J	37	[32, 42]	33.5	[30, 38]	
K	197	[192, 201]	196.5	[190, 203]	
L	16	[13, 19]	15.8	[12, 19]	

Discussion

- Using the structured 3D photogrammetry technique as proposed in this study, posture estimations can be performed with greatly reduced uncertainties and sources of errors
- New NBP angles are comparable to NASA STD, but the extremity angles are significantly different
- Significant variability was observed in NBP between test trials. However, the specific association with the preceding effort types were not observed
- Individual variations, specifically the anthropometry and gender association with the NBP has not been quantified in this study
- This technique also represents NBP in 3D body shape manikin, which can be directly embedded in CAD and virtual accommodation tests
- The concept of NBP has been adopted as a reference posture for driver seat design in the commercial automobile industry (NASA, 2013)
- Overall the outcome of this study can help to improve the design of the spaceflight hardware and suits
  - Reference posture for spacesuit
  - Computer console and workstation design
  - Occupancy volume estimation for habitat

Contact Information



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