Analysis of Human Postural Control in the Demonstrator Spacesuit

Patrick McKeen[1], Leia Stirling[1,2]
[1]MIT Department of Aeronautics and Astronautics, Man Vehicle Lab
[2]Institute for Medical Engineering & Science

Introduction

Manned space flight commonly requires extravehicular activities (EVAs), where the crewmembers must exit the capsule. Spacesuits are used to provide life support during EVAs. However, they limit the natural range of motion, which can affect comfort and performance, and may increase injury risk. With future manned missions to the Moon and Mars, it is important to understand any negative impacts on stance and gait, which are important for planetary environments.

In this study, we examined how balance and postural control were affected when wearing the soft-material David Clark Company Incorporated (DCCI) Demonstrator suit.

Experimental Methods



Figure 1: Subject during testing in DCCI Demonstrator suit

This study examined a case study with one subject that was familiar with the DCCI Demonstrator suit. The suit was pressurized to 4 psi and the subject performed a series of tests, including walking across the room (seen in Figure 1) and standing (double support and single support on each leg). Each task was conducted suited and unsuited, 12 times each. In half of these trials, data was collected from Novel Pliance pressure-sensitive insoles. Pressure data were imported into MATLAB and zeroed for suited trials based on calibrating data when each foot was lifted off the ground. A minimum threshold was enforced to remove noise in the readings due to extraneous contact. The data was evaluated by creating heatmaps of the sensors and stabilograms tracing the motion of the center of pressure, as well as force plots.

Stabilograms were created in Matlab using the processed pressure data. Left and right stance stabilograms were created only from the readings from the relevant foot. Each trace in the stabilogram (from each individual trial) was evaluated using five metrics[1], as shown in Figure 2. For each of these metrics, the impact of stances and suited conditions was evaluated using an ANOVA. Post-hoc comparisons used a 2-sample t-test with a Bonferroni correction applied.

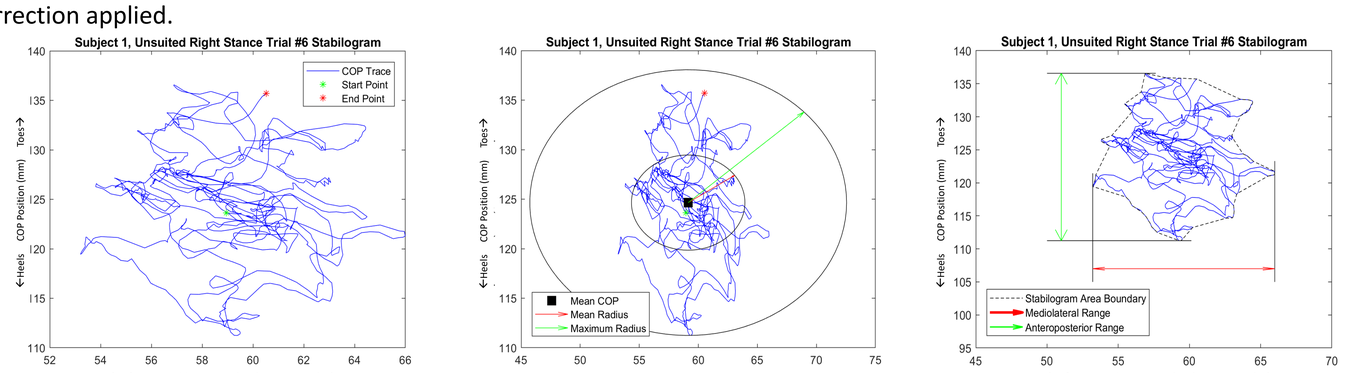


Figure 2: Stabilogram evaluation metrics

Results and Discussion

The stabilogram metrics are shown in Table 1. Separate ANOVA models supported an interaction effect of stance and suit condition for Mediolateral (ML) Range ($F(5,30)=10.83, p=0.0003$) and Bounding Area ($F(5,30)=9.14, p=0.0008$). The models did not support an interaction effect between stance and suited condition for Mean Radius ($F(5,30)=1.1, p=0.3447$), Maximum Radius ($F(5,30)=0.18, p=0.8372$), and Anteroposterior (AP) Range ($F(5,30)=0.2, p=0.8162$). Main effects of stance were observed for Mean Radius ($F(2,30)=13.76, p=0.0001$), Maximum Radius ($F(2,30)=7.31, p=0.0026$), and AP Range ($F(2,30)=9.74, p=0.0006$). Main effects of suited condition were also observed for Mean Radius ($F(1,30)=20.79, p=0.0001$), Maximum Radius ($F(1,30)=14.62, p=0.0006$), and AP Range ($F(1,30)=15.11, p=0.0005$). Full results are shown in Tables 2 and 3.

The mean and maximum radii of the stabilograms, as well as anteroposterior range, increased when the subject was suited, which may indicate a difficulty balancing, particularly along the anteroposterior axis. The other two metrics also increase in suited conditions when on a single foot. This decrease in balance may be associated with difficulty in postural control. One potential source of this difficulty is that the suit may limit the small motor actions at the ankle, preventing postural corrections. Other contributing factors include the suit affecting the subject's center of mass, which may be compounded by the structural damping effect of the suit—when the subject adjusts their position for balance, the suit may not move with them, complicating the adjustments for postural control.

It is also worth noting that ML Range and Bounding Area, the two metrics most influenced by ML sway (the stabilograms tend to have larger AP sway, so the radii metrics are less affected), are also the metrics that show interaction effects. This suggests that postural control varies between the ML and AP axes. This is supported in the data as the metrics dominated by AP movement are all affected by suited condition. However, the metrics affected by ML movement are affected by the suited condition only during single support. This likely results from the wider base of support in double supported cases.

Difficulties balancing may limit performance when wearing spacesuits. This could affect gait, matching trouble walking reported by the subject during testing. This will complicate future planetary missions, where walking will be necessary and these performance limits could impact the efficacy of the mission. Improving spacesuit designs to minimize the factors responsible for balance loss could improve future mission operations.

	Double (D) Stance		Left (L) Stance		Right (R) Stance	
	Unsuited	Suited	Unsuited	Suited	Unsuited	Suited
Mean Radius (mm)	2.9(1.0)	4.3(2.1)	5.1(0.7)	6.8(2.0)	4.7(0.8)	7.7(0.8)
Bounding Area (mm^2)	21.7(9.5)	26.2(12.9)	190.2(30.4)	366.6(130.5)	178.5(37.6)	409.9(89.2)
Max Radius	9.0(2.8)	15.2(7.9)	16.6(3.3)	20.9(4.0)	13.8(3.3)	19.9(2.4)
AP Range	15.7(4.2)	24.3(11.2)	27.9(5.7)	34.7(6.5)	23.5(5.6)	33.8(3.3)
ML Range	2.7(0.7)	3.0(0.5)	12.8(1.6)	19.8(3.0)	13.7(2.6)	19.5(1.4)

Table 1: Numerical metrics from stabilograms. Results are displayed in the format: mean (S.D.). The meanings of the metrics can be seen in Figure 4.

	D vs L Stance		D vs R Stance		L vs R Stance		Suited vs Unsuited	
	t	p	t	p	t	p	t	p
Mean Radius	-3.4177	**0.0025**	-3.7073	**0.0012**	-0.3396	0.7374	3.4404	**0.0016**
Max Radius	-2.9558	**0.0073**	-2.1068	0.0468	1.1003	0.2831	3.3244	**0.0021**
AP Range	-3.4284	**0.0024**	-2.6050	**0.0162**	0.9560	0.3494	3.2090	**0.0029**

Table 2: Post-hoc t-test results for metrics with no interaction between stance and suited condition

	Suited D vs L Stance		Suited D vs R Stance		Suited L vs R Stance		Unsuited D vs L Stance		Unsuited D vs R Stance		Unsuited L vs R Stance		D Stance Suited vs Unsuited		L Stance Suited vs Unsuited		R Stance Suited vs Unsuited	
	t	p	t	p	t	p	t	p	t	p	t	p	t	p	t	P	t	p
Area	-6.3591	**0.0001**	-10.4228	**<0.0001**	-0.6708	0.5176	-12.9660	**<0.0001**	-9.9104	**<0.0001**	0.5952	0.5649	0.6798	0.5121	3.2238	0.0091	5.8528	**0.0002**
ML Range	-13.3751	**<0.0001**	-27.6516	**<0.0001**	0.2422	0.8135	-14.3040	**<0.0001**	-9.7547	**<0.0001**	-0.6866	0.5079	0.8107	0.4364	5.0319	**0.0005**	4.7832	**0.0007**

Table 3: Post-hoc t-test results for metrics with interaction between stance and suited condition

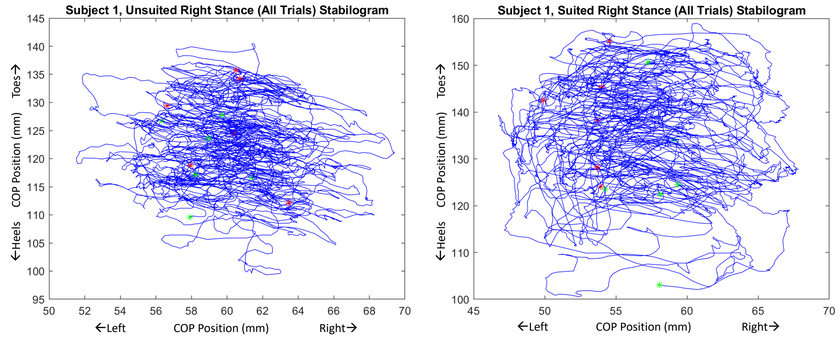


Figure 3: Example stabilograms. Each blue line is a trace from a single trial, running between the green and red stars

Future Work

The extent of the balance loss in other contexts (e.g., gait, mission tasks) should be explored. The effect of these balance limits on gait, particularly over uneven terrain or unexpected events, is worth consideration. Further exploration of the source of the balance loss is also warranted. Determining whether improved mobility of the ankle, center of mass location, or coupling between the subject and the suit assist in balance will allow improvements to spacesuit design.

The exact nature of the difficulty should also be qualified. Further testing to determine any difference between the mediolateral and anteroposterior axes should be considered, for example. Understanding exactly how the balance is affected will enable smarter solutions and improvements.

References:

[1] Priplata, A. A., Niemi, J. B., Harry, J. D., Lipsitz, L. A., & Collins, J. J. (2003). Vibrating insoles and balance control in elderly people. *The Lancet, 362*(9390), 1123-1124. doi:10.1016/s0140-6736(03)14470-4

Acknowledgements:

DCCIThank you to everyone at DCCI for assisting with testing. Also thanks to Aditi Gupta and Richard Fineman in the MVL for their help in running the trials.

Funding: Support:
NASA Award NNX15AR20G