# Supplementary Material

## 1 CUBIC SMOOTHING SPLINE FIT

For obtaining missing data (joint acceleration, base link velocity and acceleration) we apply a cubic smoothing spline fit the source data De Boor (1978). The smoothing spline minimizes the term

$$p\sum_{j=i}^{n} w_j|y_j - f(x_j)|^2 + (1-p)\int \lambda(t)|D^2 f(t)|^2 dt \tag{S1}$$

where the first and second term are for the error and roughness measure, respectively. The second derivative of $f$ is denoted as $D^2 f$. We apply a smoothing parameter $p$ of 0.99.

## 2 EXPERIMENTAL DATA

**Table S1. Differences in joint angles.** The table compares the differences of the actuated joints during the StS-transitions among all trials for the two different protocols $P1$-lower chair height and $P2$-increased ankle distance. For each joint the avg. [std] and the L2 norm of the difference in degrees between the actual and simulated data are reported.

| | Trial | Hip Joint | | Knee Joint | | Ankle Joint | |
|---|---|---|---|---|---|---|---|
| **Protocol 1** | 115% | 0.98 [1.3] | 9.14 | 0.07 [0.11] | 0.72 | 0.04 [0.03] | 0.29 |
| | 110% | 3.41 [3.24] | 25.94 | 0.28 [0.43] | 2.83 | 0.15 [0.14] | 1.14 |
| | 105% | 2.12 [2.66] | 16.14 | 0.01 [0.01] | 0.07 | 0.01 [0.01] | 0.05 |
| | 100% | 9.51 [13.81] | 78.69 | 0.04 [0.06] | 0.34 | 0.02 [0.02] | 0.16 |
| **Protocol 2** | 25% | 0.42 [0.44] | 3.44 | 0.13 [0.22] | 1.44 | 0.08 [0.07] | 0.57 |
| | 30% | 0.77 [0.62] | 5.46 | 0.19 [0.33] | 2.1 | 0.12 [0.1] | 0.83 |
| | 35% | 1.51 [1.97] | 13.14 | 0.1 [0.17] | 1.07 | 0.07 [0.06] | 0.51 |
| | 40% | 2.43 [2.43] | 17.73 | 0.06 [0.08] | 0.54 | 0.05 [0.04] | 0.33 |

| | | Torso Joint | | Shoulder Joint | | Elbow Joint | |
|---|---|---|---|---|---|---|---|
| **Protocol 1** | 115% | 0.11 [0.09] | 0.8 | 0.09 [0.13] | 0.88 | 0.09, [0.13] | 0.88 |
| | 110% | 0.19 [0.24] | 1.68 | 0.83 [0.88] | 6.67 | 0.15, [0.34] | 2.03 |
| | 105% | 0.54 [0.93] | 5.1 | 0.75 [0.73] | 4.96 | 0.1, [0.14] | 0.8 |
| | 100% | 0.72 [0.86] | 5.31 | 1.98 [2.49] | 15.06 | 0.11, [0.18] | 0.97 |
| **Protocol 2** | 25% | 0.11 [0.06] | 0.71 | 0.38 [0.52] | 3.66 | 0.07 [0.08] | 0.62 |
| | 30% | 0.4 [0.45] | 3.34 | 1.6 [1.93] | 13.78 | 0.15 [0.34] | 2.03 |
| | 35% | 1.11 [1.49] | 9.84 | 2.01 [2.91] | 18.71 | 0.15 [0.24] | 1.48 |
| | 40% | 1.62 [1.36] | 10.93 | 6.72 [6.95] | 49.87 | 1.35 [2.12] | 12.97 |

**Table S2. Results based on the point based metrics.** The table shows the distance from the location of the corresponding point based metric to the Base of Support (BoS) among all trials for the two different protocols $P1$-lower chair height and $P2$-increased ankle distance. For each metric and trial the aggregate functions report the avg. [std], minima, maxima, percentage [inside, outside] of the BoS and the integrated values normalized by experimental duration.

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **ZMP** | **Protocol 1** | 115% | 3.33 [2.59] | -0.81 | 7.8 | [92.5, 7.5] | 170.17 |
| | | 110% | 2.13 [4.49] | -7.16 | 7.9 | [67.07, 32.93] | 219.38 |
| | | 105% | 0.68 [4.73] | -7.88 | 7.8 | [56.25, 43.75] | 213.01 |
| | | 100% | -1.43 [8.78] | -23.23 | 8.05 | [63.06, 36.94] | 318.68 |
| | **Protocol 2** | 25% | 4.47 [2.43] | -0.71 | 7.85 | [93.51, 6.49] | 224.88 |
| | | 30% | 2.79 [3.15] | -4.14 | 7.97 | [83.33, 16.67] | 183.34 |
| | | 35% | 0.12 [4.41] | -7.21 | 7.84 | [48.89, 51.11] | 187.42 |
| | | 40% | -1.75 [6.73] | -18.28 | 7.79 | [39.36, 60.64] | 279.94 |

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **FPE** | **Protocol 1** | 115% | 5.31 [1.26] | 2.92 | 7.74 | [100.0, 0.0] | 263.46 |
| | | 110% | 3.03 [2.41] | -1.28 | 7.67 | [82.93, 17.07] | 163.56 |
| | | 105% | 1.96 [2.54] | -1.91 | 7.7 | [70.54, 29.46] | 120.97 |
| | | 100% | -2.39 [7.37] | -17.48 | 7.54 | [61.26, 38.74] | 260.06 |
| | **Protocol 2** | 25% | 6.02 [1.25] | 3.13 | 7.9 | [100.0, 0.0] | 297.9 |
| | | 30% | 5.03 [1.31] | 2.48 | 7.7 | [100.0, 0.0] | 251.04 |
| | | 35% | 4.12 [2.06] | 0.36 | 7.75 | [100.0, 0.0] | 205.61 |
| | | 40% | 1.49 [2.96] | -3.62 | 7.44 | [64.89, 35.11] | 123.26 |

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **CP** | **Protocol 1** | 115% | 5.2 [1.11] | 3.55 | 7.64 | [100.0, 0.0] | 258.09 |
| | | 110% | 2.94 [2.97] | -2.78 | 7.58 | [78.05, 21.95] | 182.11 |
| | | 105% | 1.74 [2.96] | -3.32 | 7.7 | [67.86, 32.14] | 135.25 |
| | | 100% | -2.15 [7.63] | -18.87 | 7.65 | [57.66, 42.34] | 264.79 |
| | **Protocol 2** | 25% | 5.83 [0.85] | 3.81 | 7.68 | [100.0, 0.0] | 288.53 |
| | | 30% | 4.75 [1.29] | 2.13 | 7.72 | [100.0, 0.0] | 237.14 |
| | | 35% | 3.72 [2.5] | -0.28 | 7.78 | [95.56, 4.44] | 186.12 |
| | | 40% | 1.34 [3.34] | -3.17 | 7.15 | [54.26, 45.74] | 140.79 |

**Table S3. Results of the COMx location and the normalized COM velocity.** The two table show the results of the calculated metrics for COM(x) location relative to the sitting contact and the normalized COM velocity among all trials for the two different protocols $P1$-lower chair height and $P2$-increased ankle distance. For each metric and trial the aggregate functions report (if applicable) the avg. [std], minima, maxima, percentage [inside, outside] of the BoS and the integrated values normalized by experimental duration.

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **COM(x) Location** | **Protocol 1** | 115% | 4.54 [2.48] | -0.38 | 7.96 | [88.75, 11.25] | 227.29 |
| | | 110% | 6.51 [4.34] | -0.34 | 14.18 | [89.02, 10.98] | 322.84 |
| | | 105% | 4.42 [5.46] | -3.25 | 14.29 | [66.96, 33.04] | 219.29 |
| | | 100% | 8.08 [9.17] | -2.36 | 27.27 | [69.37, 30.63] | 398.29 |
| | **Protocol 2** | 25% | 3.82 [1.96] | -0.38 | 5.92 | [89.61, 10.39] | 189.26 |
| | | 30% | 5.42 [3.46] | -0.74 | 9.55 | [83.33, 16.67] | 271.6 |
| | | 35% | 6.99 [4.65] | -0.5 | 14.36 | [90.0, 10.0] | 349.22 |
| | | 40% | 9.95 [6.31] | -2.38 | 18.03 | [89.36, 10.64] | 494.44 |

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **Norm. COM Velocity** | **Protocol 1** | 115% | 0.11 [0.04] | 0.02 | 0.19 | [100.0, 0.0] | 5.48 |
| | | 110% | 0.13 [0.05] | 0.02 | 0.21 | [100.0, 0.0] | 6.68 |
| | | 105% | 0.14 [0.08] | 0.01 | 0.29 | [100.0, 0.0] | 7.14 |
| | | 100% | 0.18 [0.11] | 0 | 0.37 | [100.0, 0.0] | 8.91 |
| | **Protocol 2** | 25% | 0.08 [0.05] | 0.02 | 0.16 | [100.0, 0.0] | 4.01 |
| | | 30% | 0.1 [0.05] | 0.03 | 0.18 | [100.0, 0.0] | 5.07 |
| | | 35% | 0.13 [0.06] | 0.02 | 0.24 | [100.0, 0.0] | 6.35 |
| | | 40% | 0.15 [0.1] | 0.03 | 0.38 | [100.0, 0.0] | 7.63 |

**Table S4. Minimum and maximum forces acting on the robot and chair.** The table shows the z-forces in Nm measured by chair and force sensors in the robotic feet for the various difficulty settings among both trials.

| | | Protocol 1 | | | | Protocol 2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **115%** | **110%** | **105%** | **100%** | **25%** | **30%** | **35%** | **40%** |
| **Robot** | **Min** | -123.8 | -112.4 | -136.6 | -168.4 | -183.4 | -173.4 | -163.8 | -129 |
| | **Max** | 1012 | 798.2 | 773.2 | 703.2 | 1005.6 | 956.2 | 818.2 | 1048.2 |
| **Chair** | **Min** | 0.32 | 0.1 | -1.19 | -3.34 | 0.52 | 0.84 | 0 | -28.18 |
| | **Max** | 659.61 | 659.56 | 901.08 | 766.08 | 623.81 | 662.91 | 678.95 | 854.18 |

**Table S5. Results based on the Angular Momentum (AM) metrics.** The table reports the experimental results for the AM normalized by $m \times l^2$ where $m$ is the mass and $l$ the total leg length of the robot among all trials for the two different protocols $P1$-lower chair height and $P2$-increased ankle distance. For each metric and trial the aggregate functions report the avg. [std], minima, maxima, percentage [positive, negative] of the BoS and the integrated values normalized by experimental duration.

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **Norm. AM(x)** | **Protocol 1** | 115% | 0.0013 [0.0008] | -0.0029 | 0.0022 | [38.75, 61.25] | 0.0632 |
| | | 110% | 0.0017 [0.0015] | -0.0052 | 0.0017 | [56.0976, 43.9024] | 0.0851 |
| | | 105% | 0.0005 [0.0005] | -0.0018 | 0.0014 | [47.3214, 52.6786] | 0.0271 |
| | | 100% | 0.0061 [0.0069] | -0.0233 | 0.0009 | [20.7207, 79.2793] | 0.3013 |
| | **Protocol 2** | 25% | 0.0025 [0.0014] | -0.0049 | 0.0045 | [64.9351, 35.0649] | 0.1228 |
| | | 30% | 0.0043 [0.0025] | -0.0071 | 0.008 | [36.9048, 63.0952] | 0.2148 |
| | | 35% | 0.0022 [0.0016] | -0.0057 | 0.0024 | [50.0, 50.0] | 0.1083 |
| | | 40% | 0.001 [0.0008] | -0.0025 | 0.0012 | [40.4255, 59.5745] | 0.0483 |

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **Norm. AM(y)** | **Protocol 1** | 115% | 0.0364 [0.0208] | -0.0916 | 0.0423 | [61.25, 38.75] | 1.8246 |
| | | 110% | 0.0339 [0.0124] | -0.0558 | 0.0477 | [67.0732, 32.9268] | 1.6903 |
| | | 105% | 0.0243 [0.0154] | -0.0469 | 0.0579 | [67.8571, 32.1429] | 1.2193 |
| | | 100% | 0.0386 [0.0306] | -0.0765 | 0.1091 | [80.1802, 19.8198] | 1.9105 |
| | **Protocol 2** | 25% | 0.0331 [0.0178] | -0.0744 | 0.039 | [63.6364, 36.3636] | 1.6467 |
| | | 30% | 0.0325 [0.0197] | -0.0685 | 0.0533 | [69.0476, 30.9524] | 1.6375 |
| | | 35% | 0.0333 [0.0273] | -0.0833 | 0.0784 | [67.7778, 32.2222] | 1.6726 |
| | | 40% | 0.0379 [0.0234] | -0.0481 | 0.097 | [57.4468, 42.5532] | 1.8912 |

| | | Trial | Average | Min | Max | Percentage | Integral |
|---|---|---|---|---|---|---|---|
| **Norm. AM(z)** | **Protocol 1** | 115% | 0.0006 [0.0004] | -0.0013 | 0.0014 | [46.25, 53.75] | 0.0326 |
| | | 110% | 0.0005 [0.0003] | -0.001 | 0.001 | [63.4146, 36.5854] | 0.0237 |
| | | 105% | 0.0003 [0.0003] | -0.0015 | 0.0007 | [41.0714, 58.9286] | 0.0171 |
| | | 100% | 0.0041 [0.0068] | -0.0017 | 0.0234 | [59.4595, 40.5405] | 0.201 |
| | **Protocol 2** | 25% | 0.0008 [0.0009] | -0.0035 | 0.0011 | [45.4545, 54.5455] | 0.0398 |
| | | 30% | 0.0007 [0.0006] | -0.0024 | 0.002 | [48.8095, 51.1905] | 0.0347 |
| | | 35% | 0.0006 [0.0008] | -0.0037 | 0.0011 | [41.1111, 58.8889] | 0.0311 |
| | | 40% | 0.0008 [0.0006] | -0.0024 | 0.0018 | [52.1277, 47.8723] | 0.0379 |

## REFERENCES

De Boor, C. (1978). *A practical guide to splines*, vol. 27 (springer-verlag New York)