Supplementary Material

MeshMonk: open-source large-scale intensive 3D phenotyping

Julie D. White\*, Alejandra Ortega-Castrillón, Arslan A. Zaidi, Harry Matthews, Omid Ekrami, Jonatan Snyders, Stefan Van Dongen, Mark D. Shriver, Peter Claes\*

**\* Correspondence:** Corresponding Authors: jdw345@psu.edu; peter.claes@kuleuven.be

# Supplementary Data

**Supplementary Table 1.** Descriptive data for the validation sample used. These data are included only to describe the variation present in the sample and were not used as covariates in statistical analyses.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ID | Sex | Age | Height (cm) | Weight (kg) | Self-identified population | Camera |
| 61549 | F | 33 | 155.00 | 48.00 | Admixed African and European | 2006, 2-pod |
| 61587 | F | 20 | 158.00 | 43.00 | Italian | 2006, 2-pod |
| 61622 | M | 21 | 175.00 | 71.99 | Italian | 2006, 2-pod |
| 62102 | M | 22 | 178.00 | 60.01 | Polish | 2006, 2-pod |
| 62588 | M | 21 | 172.00 | 57.02 | Portuguese | 2006, 2-pod |
| 62633 | M | 41 | 176.00 | 76.02 | Portuguese | 2006, 2-pod |
| 62659 | F | 28 | 169.00 | 57.02 | Portuguese | 2006, 2-pod |
| 62677 | M | 24 | 175.00 | 65.00 | Portuguese | 2006, 2-pod |
| 62695 | F | 30 | 165.00 | 66.00 | Portuguese | 2006, 2-pod |
| 63096 | F | 20 | 165.10 | 57.15 | Irish | 2006, 2-pod |
| 63123 | F | 27 | 165.00 | 57.15 | Irish | 2006, 2-pod |
| 63151 | F | 43 | 165.10 | 69.85 | Irish | 2006, 2-pod |
| 63156 | M | 19 | 184.00 | 60.33 | Irish | 2006, 2-pod |
| 63173 | M | 19 | 180.00 | 66.00 | Irish | 2006, 2-pod |
| 131213 | M | 23 | 172.55 | 72.85 | Broadly European | 2013, 2-pod |
| 140241 | F | 33 | 160.70 | 57.40 | Unknown | 2014, 3-pod |
| 140268 | M | 19 | 179.00 | 103.80 | Mixed European and European American | 2014, 3-pod |
| 140679 | M | 62 | 166.00 | 63.30 | Mixed European and European American | 2014, 3-pod |
| 140721 | F | 26 | 165.00 | 101.30 | Mixed European and European American | 2014, 3-pod |
| 140739 | F | 73 | 169.00 | 83.00 | Mixed European and European American | 2014, 3-pod |
| 140956 | M | 21 | 168.60 | 70.80 | Broadly European | 2014, 3-pod |
| 141280 | F | 79 | 149.86 | 70.31 | Broadly European | 2014, 3-pod |
| 141527 | F | 66 | 170.18 | 97.07 | Mixed European and European American | 2014, 3-pod |
| 141563 | F | 24 | 154.94 | 52.16 | Mixed European and European American | 2014, 3-pod |
| 141706 | F | 63 | 170.18 | 81.65 | Broadly European | 2014, 3-pod |
| 141713 | F | 53 | 162.56 | 86.18 | Broadly European | 2014, 3-pod |
| 141869 | F | 25 | 152.40 | 46.72 | Mixed European and European American | 2014, 3-pod |
| 141875 | F | 55 | 165.10 | 62.60 | Mixed European and European American | 2014, 3-pod |
| 141913 | F | 20 | 162.56 | 68.04 | Mixed European and European American | 2014, 3-pod |
| 141979 | F | 65 | 157.48 | 54.43 | Mixed European and European American | 2014, 3-pod |
| 143007 | F | 27 | 156.40 | 62.40 | Mixed European and European American | 2014, 3-pod |
| 143076 | F | 19 | 181.00 | 68.40 | Mixed European and European American | 2014, 3-pod |
| 143093 | F | 18 | 179.00 | 65.00 | Broadly European | 2014, 3-pod |
| 143126 | F | 20 | 162.30 | 98.90 | Broadly European | 2014, 3-pod |
| 143162 | F | 19 | 170.00 | 75.70 | Broadly European | 2014, 3-pod |
| 143221 | F | 53 | 164.00 | 50.80 | Mixed European, Jewish | 2014, 3-pod |
| 143235 | F | 22 | 169.90 | 55.00 | Mixed European and European American | 2014, 3-pod |
| 143340 | M | 28 | 174.00 | 65.30 | Broadly European | 2014, 3-pod |
| 143578 | F | 23 | 161.00 | 78.20 | Broadly European | 2014, 3-pod |
| 143651 | F | 19 | 162.00 | 59.40 | Mixed European, Jewish | 2014, 3-pod |
| 143670 | F | 21 | 164.60 | 67.20 | Mixed European and European American | 2014, 3-pod |

# Supplementary Figures and Tables

## Supplementary Figures

## Supplementary Tables

**Supplementary Table X**. Standard deviation (mm) of landmark iterations along the x, y, and z dimension, averaged across images for each landmark. The means of each observer as well as the inter-observer error are reported in Table X of the accompanying manuscript.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Landmark* | *Standard deviation (mm)* | | | | | | | | | | | |
| *Observer AJ* | | | | *Observer JW* | | | | *Inter-observer* | | | |
| *X* | *Y* | *Z* | *Mean* | *X* | *Y* | *Z* | *Mean* | *X* | *Y* | *Z* | *Mean* |
| *Alar curvature left* | 0.2069 | 0.6795 | 0.9196 | **0.6020** | 0.1471 | 0.5472 | 0.6074 | **0.4339** | 0.1222 | 0.3752 | 0.4227 | **0.3067** |
| *Alar curvature right* | 0.2076 | 0.7503 | 0.9333 | **0.6304** | 0.1327 | 0.4612 | 0.5379 | **0.3773** | 0.1219 | 0.3369 | 0.5273 | **0.3287** |
| *Chelion left* | 0.8601 | 0.5386 | 0.4255 | **0.6080** | 0.6703 | 0.3527 | 0.3184 | **0.4472** | 0.5948 | 0.2965 | 0.3631 | **0.4182** |
| *Chelion right* | 0.8074 | 0.4917 | 0.5016 | **0.6002** | 0.7412 | 0.3465 | 0.3924 | **0.4934** | 0.4269 | 0.2712 | 0.1971 | **0.2984** |
| *Crista philtri left* | 0.5461 | 0.6676 | 0.2912 | **0.5016** | 0.4327 | 0.2984 | 0.1812 | **0.3041** | 0.5169 | 0.4584 | 0.1890 | **0.3881** |
| *Crista philtri right* | 0.5518 | 0.7146 | 0.3409 | **0.5358** | 0.4654 | 0.2520 | 0.1671 | **0.2949** | 0.6536 | 0.5698 | 0.1976 | **0.4737** |
| *Endocanthion left* | 0.9219 | 0.6269 | 0.6852 | **0.7447** | 0.5506 | 0.3861 | 0.3749 | **0.4372** | 0.5882 | 0.3286 | 0.3917 | **0.4362** |
| *Endocanthion right* | 1.1879 | 0.5003 | 0.6209 | **0.7697** | 0.5617 | 0.3647 | 0.4121 | **0.4462** | 0.4828 | 0.2689 | 0.3306 | **0.3608** |
| *Exocanthion left* | 0.6899 | 0.5058 | 0.5631 | **0.5863** | 0.5032 | 0.4039 | 0.4069 | **0.4380** | 0.3635 | 0.2705 | 0.2498 | **0.2946** |
| *Exocanthion right* | 0.7402 | 0.5897 | 0.6330 | **0.6543** | 0.4346 | 0.2882 | 0.3507 | **0.3579** | 0.3524 | 0.2374 | 0.2668 | **0.2855** |
| *Glabella* | 0.5627 | 0.8658 | 0.2998 | **0.5761** | 0.4532 | 1.1696 | 0.4414 | **0.6881** | 0.4175 | 0.6913 | 0.2536 | **0.4542** |
| *Labiale inferius* | 0.5214 | 0.6100 | 0.3782 | **0.5032** | 0.4183 | 0.3355 | 0.1987 | **0.3175** | 0.5355 | 0.8468 | 0.3749 | **0.5857** |
| *Labiale superius* | 0.4673 | 0.5861 | 0.2228 | **0.4254** | 0.2968 | 0.3757 | 0.1274 | **0.2666** | 0.3752 | 0.4534 | 0.1269 | **0.3185** |
| *Nasion* | 0.3302 | 0.9321 | 0.3471 | **0.5365** | 0.3132 | 0.8478 | 0.4595 | **0.5402** | 0.3891 | 0.8151 | 0.2772 | **0.4938** |
| *Pogonion* | 0.6464 | 1.2742 | 0.5419 | **0.8208** | 0.6220 | 1.1558 | 0.5000 | **0.7593** | 0.7110 | 0.7572 | 0.3278 | **0.5987** |
| *Pronasale* | 0.4185 | 0.7104 | 0.2491 | **0.4593** | 0.2994 | 0.4423 | 0.2053 | **0.3157** | 0.2896 | 0.4927 | 0.2147 | **0.3323** |
| *Subalare left* | 0.5524 | 0.3630 | 0.5900 | **0.5018** | 0.5157 | 0.3075 | 0.4553 | **0.4262** | 0.4764 | 0.2554 | 0.4697 | **0.4005** |
| *Subalare right* | 0.5767 | 0.3144 | 0.5739 | **0.4883** | 0.6422 | 0.3214 | 0.4909 | **0.4848** | 0.4979 | 0.3147 | 0.4723 | **0.4283** |
| *Subnasale* | 0.3765 | 0.6527 | 0.3219 | **0.4504** | 0.3342 | 0.7196 | 0.3546 | **0.4695** | 0.1766 | 0.5530 | 0.3143 | **0.3480** |
| *Mean* | **0.5880** | **0.6512** | **0.4968** | **0.5787** | **0.4492** | **0.4935** | **0.3675** | **0.4367** | **0.4259** | **0.4523** | **0.3141** | **0.3974** |

**Table X. Comparison of inter-observer errors.** Standard deviation between the average of AZ’s manual landmarks and JW’s manual landmarks constitute the “manual” inter-observer error. The standard deviation between the automatic landmarks trained using AZ’s manual landmark average and the automatic landmarks trained using JW’s manual landmark average constitute the “auto” inter-observer error.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Landmark* | *Standard deviation (mm)* | | | | | | | |
| *X* | | *Y* | | *Z* | | *Mean* | | |
| *Manual* | *Auto* | *Manual* | *Auto* | *Manual* | *Auto* | *Manual* | *Auto* | |
| *Alar curvature left* | 0.1222 | 0.0328 | 0.3752 | 0.0968 | 0.4227 | 0.0888 | 0.3067 | 0.0728 | |
| *Alar curvature right* | 0.1219 | 0.0809 | 0.3369 | 0.1702 | 0.5273 | 0.3887 | 0.3287 | 0.2133 | |
| *Chelion left* | 0.5948 | 0.3528 | 0.2965 | 0.1024 | 0.3631 | 0.1441 | 0.4182 | 0.1998 | |
| *Chelion right* | 0.4269 | 0.0999 | 0.2712 | 0.0576 | 0.1971 | 0.0335 | 0.2984 | 0.0637 | |
| *Crista philtri left* | 0.5169 | 0.4761 | 0.4584 | 0.4780 | 0.1890 | 0.1891 | 0.3881 | 0.3811 | |
| *Crista philtri right* | 0.6536 | 0.5451 | 0.5698 | 0.5632 | 0.1976 | 0.2333 | 0.4737 | 0.4472 | |
| *Endocanthion left* | 0.5882 | 0.5029 | 0.3286 | 0.2057 | 0.3917 | 0.3426 | 0.4362 | 0.3504 | |
| *Endocanthion right* | 0.4828 | 0.4507 | 0.2689 | 0.1215 | 0.3306 | 0.2284 | 0.3608 | 0.2669 | |
| *Exocanthion left* | 0.3635 | 0.0389 | 0.2705 | 0.1470 | 0.2498 | 0.0564 | 0.2946 | 0.0808 | |
| *Exocanthion right* | 0.3524 | 0.1375 | 0.2374 | 0.0581 | 0.2668 | 0.0928 | 0.2855 | 0.0961 | |
| *Glabella* | 0.4175 | 0.3569 | 0.6913 | 0.3757 | 0.2536 | 0.1489 | 0.4542 | 0.2938 | |
| *Labiale inferius* | 0.5355 | 0.4984 | 0.8468 | 0.8805 | 0.3749 | 0.3531 | 0.5857 | 0.5773 | |
| *Labiale superius* | 0.3752 | 0.3560 | 0.4534 | 0.4481 | 0.1269 | 0.1827 | 0.3185 | 0.3289 | |
| *Nasion* | 0.3891 | 0.3114 | 0.8151 | 0.5207 | 0.2772 | 0.2212 | 0.4938 | 0.3511 | |
| *Pogonion* | 0.7110 | 0.6219 | 0.7572 | 0.2958 | 0.3278 | 0.1259 | 0.5987 | 0.3478 | |
| *Pronasale* | 0.2896 | 0.2307 | 0.4927 | 0.3302 | 0.2147 | 0.1517 | 0.3323 | 0.2376 | |
| *Subalare left* | 0.4764 | 0.4415 | 0.2554 | 0.1722 | 0.4697 | 0.3579 | 0.4005 | 0.3239 | |
| *Subalare right* | 0.4979 | 0.3813 | 0.3147 | 0.1788 | 0.4723 | 0.3738 | 0.4283 | 0.3113 | |
| *Subnasale* | 0.1766 | 0.0926 | 0.5530 | 0.3645 | 0.3143 | 0.1643 | 0.3480 | 0.2072 | |
| ***Mean*** | **0.4259** | **0.3162** | **0.4523** | **0.2930** | **0.3141** | **0.2041** | **0.3974** | **0.2711** | |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Landmark* | *X* | | | | *Y* | | | | *Z* | | | |
| Manual (mm) | *Auto (mm)* | *F* | *P* | *Manual (mm)* | *Auto (mm)* | *F* | *P* | *Manual (mm)* | *Auto (mm)* | *F* | *P* |
| *Alar curvature left* | 0.1222 | 0.0328 | 11.0426 | **0.0013** | 0.3752 | 0.0968 | 35.4631 | **6.61 x 10-8** | 0.4227 | 0.0888 | 51.1242 | **3.65 x 10-10** |
| *Alar curvature right* | 0.1219 | 0.0809 | 4.6816 | **0.0335** | 0.3369 | 0.1702 | 9.1797 | **0.0033** | 0.5273 | 0.3887 | 33.6410 | **1.27 x 10-7** |
| *Chelion left* | 0.5948 | 0.3528 | 5.5592 | **0.0208** | 0.2965 | 0.1024 | 6.5540 | **0.0123** | 0.3631 | 0.1441 | 4.2439 | **0.0426** |
| *Chelion right* | 0.4269 | 0.0999 | 36.1341 | **5.21 x 10-8** | 0.2712 | 0.0576 | 36.8236 | **4.09 x 10-8** | 0.1971 | 0.0335 | 11.5381 | **0.0011** |
| *Crista philtri left* | 0.5169 | 0.4761 | 22.1842 | **1.03 x 10-5** | 0.4584 | 0.4780 | 32.0376 | **2.28 x 10-7** | 0.1890 | 0.1891 | 0.6321 | 0.4289 |
| *Crista philtri right* | 0.6536 | 0.5451 | 21.1578 | **1.56 x 10-5** | 0.5698 | 0.5632 | 17.3074 | **7.94 x 10-5** | 0.1976 | 0.2333 | 0.0001 | 0.9915 |
| *Endocanthion left* | 0.5882 | 0.5029 | 20.9141 | **1.73 x 10-5** | 0.3286 | 0.2057 | 6.8084 | **0.0108** | 0.3917 | 0.3426 | 6.1201 | **0.0155** |
| *Endocanthion right* | 0.4828 | 0.4507 | 26.7346 | **1.68 x 10-6** | 0.2689 | 0.1215 | 13.8027 | **0.0004** | 0.3306 | 0.2284 | 28.3520 | **9.05 x 10-7** |
| *Exocanthion left* | 0.3635 | 0.0389 | 30.9196 | **3.44 x 10-7** | 0.2705 | 0.1470 | 23.9729 | **4.99 x 10-6** | 0.2498 | 0.0564 | 23.1588 | **6.92 x 10-6** |
| *Exocanthion right* | 0.3524 | 0.1375 | 21.8816 | **1.16 x 10-5** | 0.2374 | 0.0581 | 22.4640 | **9.17 x 10-6** | 0.2668 | 0.0928 | 16.4409 | **0.0001** |
| *Glabella* | 0.4175 | 0.3569 | 51.6989 | **3.05 x 10-10** | 0.6913 | 0.3757 | 28.9313 | **7.26 x 10-7** | 0.2536 | 0.1489 | 9.7041 | **0.0026** |
| *Labiale inferius* | 0.5355 | 0.4984 | 52.7629 | **2.20 x 10-10** | 0.8468 | 0.8805 | 11.2915 | **0.0012** | 0.3749 | 0.3531 | 0.5156 | 0.4748 |
| *Labiale superius* | 0.3752 | 0.3560 | 4.4797 | **0.0374** | 0.4534 | 0.4481 | 1.9230 | 0.1694 | 0.1269 | 0.1827 | 0.4560 | 0.5015 |
| *Nasion* | 0.3891 | 0.3114 | 38.8399 | **2.03 x 10-8** | 0.8151 | 0.5207 | 46.3141 | **1.67 x 10-9** | 0.2772 | 0.2212 | 3.9438 | 0.0505 |
| *Pogonion* | 0.7110 | 0.6219 | 40.9310 | **9.92 x 10-9** | 0.7572 | 0.2958 | 45.2473 | **2.37 x 10-9** | 0.3278 | 0.1259 | 8.2582 | **0.0052** |
| *Pronasale* | 0.2896 | 0.2307 | 102.6736 | **5.33 x 10-16** | 0.4927 | 0.3302 | 47.2076 | **1.26 x 10-9** | 0.2147 | 0.1517 | 3.5928 | 0.0616 |
| *Subalare left* | 0.4764 | 0.4415 | 14.2511 | **0.0003** | 0.2554 | 0.1722 | 4.7922 | **0.0315** | 0.4697 | 0.3579 | 9.0368 | **0.0035** |
| *Subalare right* | 0.4979 | 0.3813 | 19.2636 | **3.45 x 10-5** | 0.3147 | 0.1788 | 11.1473 | **0.0013** | 0.4723 | 0.3738 | 18.3994 | **4.97 x 10-5** |
| *Subnasale* | 0.1766 | 0.0926 | 30.9855 | **3.36 x 10-7** | 0.5530 | 0.3645 | 42.2681 | **6.33 x 10-9** | 0.3143 | 0.1643 | 21.9009 | **1.15 x 10-5** |
| *Mean* | 0.4259 | 0.3162 |  |  | 0.4523 | 0.2930 |  |  | 0.3141 | 0.2041 |  |  |