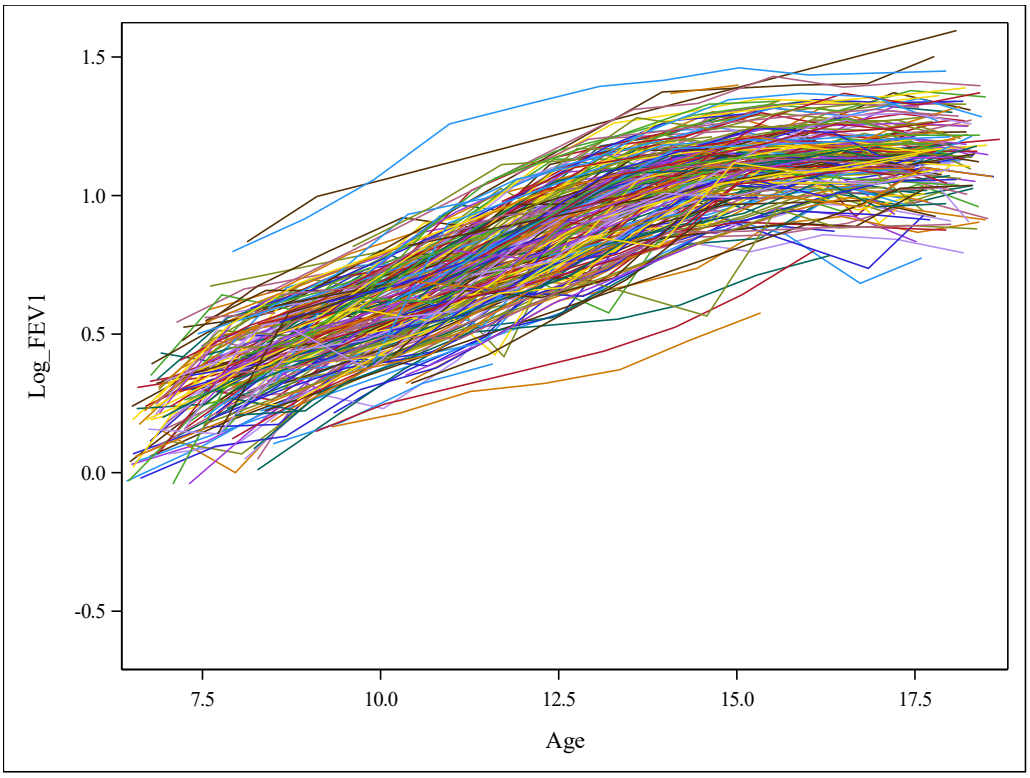
*The Six Cities Study of Air Pollution and Health was a longitudinal study designed to characterize lung growth as measured by changes in pulmonary function in children and adolescents, and the factors that influence lung function growth.

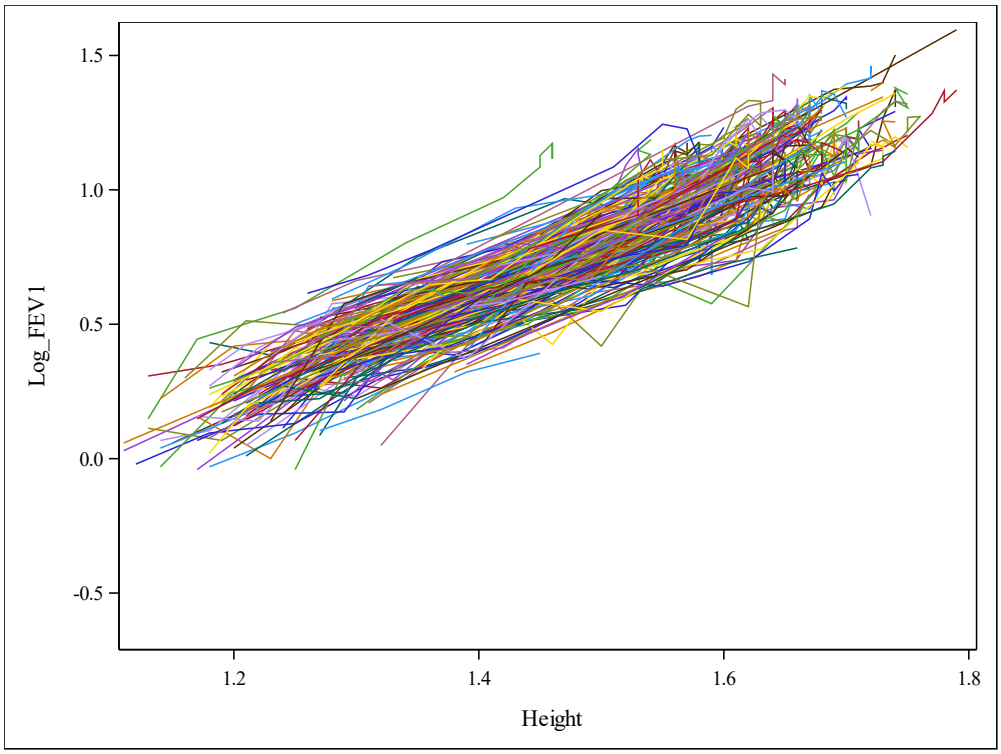
A cohort of 13,379 children born on or after 1967 was enrolled in six communities across the U.S.: Watertown (Massachusetts), Kingston and Harriman (Tennessee), a section of St. Louis (Missouri), Steubenville (Ohio), Portage (Wisconsin), and Topeka (Kansas). Most children were enrolled in the first or second grade (between the ages of six and seven) and measurements of study participants were obtained annually until graduation from high school or loss to follow-up. At each annual examination, spirometry, the measurement of pulmonary function, was performed and a respiratory health questionnaire was completed by a parent or guardian.

```
data air_pol;
input  ID Height Age INI_Height  INI_Age  Log_FEV1;
L_INI_Height = log(INI_Height);
L_Age = log(Age);
L_INI_Age = log(INI_Age);
Age_fl = floor(Age);
Height_C = Height - 1.5;
datalines;
     1     1.20      9.3415      1.20     9.3415     0.21511
     1     1.28     10.3929      1.20     9.3415     0.37156
…..
   300     1.62     15.9398      1.44     11.9617    1.08181
   300     1.62     17.0075      1.44     11.9617    1.12817
   300     1.63     17.8645      1.44     11.9617    1.16938
;
   run;

Proc SGplot data = air_pol;
series x=Age y=Log_FEV1 / group =ID LineAttrs= (pattern=1 );
run;
```




```
Proc SGplot data = air_pol;
series x=Height y=Log_FEV1 / group =ID LineAttrs= (pattern=1 );
run;
```



```
proc mixed data = air_pol covtest;
class ID;
model Log_FEV1 =  Height L_Age / solution;
random intercept L_Age /type=UN subject=ID g gcorr v vcorr;
run;
```

Convergence criteria met.

**Estimated G Matrix**

| Row | Effect | ID | Col1 | Col2 |
|---|---|---|---|---|
| 1 | Intercept | 1 | 0.04838 | -0.01823 |
| 2 | L_Age | 1 | -0.01823 | 0.008342 |

**Estimated G Correlation Matrix**

| Row | Effect | ID | Col1 | Col2 |
|---|---|---|---|---|
| 1 | Intercept | 1 | 1.0000 | -0.9073 |
| 2 | L_Age | 1 | -0.9073 | 1.0000 |

**Estimated V Matrix for ID 1**

| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
|---|---|---|---|---|---|---|---|
| 1 | 0.01203 | 0.008614 | 0.008654 | 0.008689 | 0.008720 | 0.008779 | 0.008802 |
| 2 | 0.008614 | 0.01221 | 0.008880 | 0.008989 | 0.009086 | 0.009272 | 0.009345 |
| 3 | 0.008654 | 0.008880 | 0.01255 | 0.009263 | 0.009419 | 0.009720 | 0.009840 |
| 4 | 0.008689 | 0.008989 | 0.009263 | 0.01296 | 0.009709 | 0.01011 | 0.01027 |
| 5 | 0.008720 | 0.009086 | 0.009419 | 0.009709 | 0.01343 | 0.01045 | 0.01065 |
| 6 | 0.008779 | 0.009272 | 0.009720 | 0.01011 | 0.01045 | 0.01457 | 0.01137 |

**Estimated V Matrix for ID 1**

| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
|---|---|---|---|---|---|---|---|
| 7 | 0.008802 | 0.009345 | 0.009840 | 0.01027 | 0.01065 | 0.01137 | 0.01512 |

**Estimated V Correlation Matrix for ID 1**

| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
|---|---|---|---|---|---|---|---|
| 1 | 1.0000 | 0.7106 | 0.7044 | 0.6958 | 0.6861 | 0.6629 | 0.6525 |
| 2 | 0.7106 | 1.0000 | 0.7173 | 0.7144 | 0.7095 | 0.6949 | 0.6876 |
| 3 | 0.7044 | 0.7173 | 1.0000 | 0.7263 | 0.7258 | 0.7189 | 0.7144 |
| 4 | 0.6958 | 0.7144 | 0.7263 | 1.0000 | 0.7360 | 0.7356 | 0.7335 |
| 5 | 0.6861 | 0.7095 | 0.7258 | 0.7360 | 1.0000 | 0.7473 | 0.7472 |
| 6 | 0.6629 | 0.6949 | 0.7189 | 0.7356 | 0.7473 | 1.0000 | 0.7661 |
| 7 | 0.6525 | 0.6876 | 0.7144 | 0.7335 | 0.7472 | 0.7661 | 1.0000 |

**Covariance Parameter Estimates**

| Cov Parm | Subject | Estimate | Standard Error | Z Value | Pr Z |
|---|---|---|---|---|---|
| UN(1,1) | ID | 0.04838 | 0.008880 | 5.45 | <.0001 |
| UN(2,1) | ID | -0.01823 | 0.003569 | -5.11 | <.0001 |
| UN(2,2) | ID | 0.008342 | 0.001505 | 5.54 | <.0001 |
| Residual | | 0.003462 | 0.000127 | 27.19 | <.0001 |

**Fit Statistics**

| | |
|---|---|
| -2 Res Log Likelihood | -4638.6 |

| Fit Statistics | |
|---|---|
| AIC (Smaller is Better) | -4630.6 |
| AICC (Smaller is Better) | -4630.5 |
| BIC (Smaller is Better) | -4615.8 |

```
proc mixed data = air_pol covtest;
class ID;
model Log_FEV1 =  Height L_Age / solution;
random intercept Height/type=UN subject=ID g gcorr v vcorr;
run;
```

| Fit Statistics | |
|---|---|
| -2 Res Log Likelihood | -4643.7 |
| AIC (Smaller is Better) | -4635.7 |
| AICC (Smaller is Better) | -4635.6 |
| BIC (Smaller is Better) | -4620.9 |

```
proc mixed data = air_pol covtest;
class ID;
model Log_FEV1 =  Height L_Age / solution;
random intercept Height L_Age/type=UN subject=ID g gcorr v
vcorr;
run;
```

Convergence criteria met.

| Estimated G Matrix | | | | | |
|---|---|---|---|---|---|
| Row | Effect | ID | Col1 | Col2 | Col3 |
| 1 | Intercept | 1 | 0.06208 | -0.02683 | -0.00829 |

**Estimated G Matrix**

| Row | Effect | ID | Col1 | Col2 | Col3 |
|---|---|---|---|---|---|
| 2 | Height | 1 | -0.02683 | 0.01378 | 0.004489 |
| 3 | L_Age | 1 | -0.00829 | 0.004489 | 0.000754 |

**Estimated G Correlation Matrix**

| Row | Effect | ID | Col1 | Col2 | Col3 |
|---|---|---|---|---|---|
| 1 | Intercept | 1 | 1.0000 | -0.9173 | -1.0000 |
| 2 | Height | 1 | -0.9173 | 1.0000 | 1.0000 |
| 3 | L_Age | 1 | -1.0000 | 1.0000 | 1.0000 |

**Estimated V Matrix for ID 1**

| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
|---|---|---|---|---|---|---|---|
| 1 | 0.01175 | 0.008178 | 0.008047 | 0.007921 | 0.007815 | 0.007636 | 0.007562 |
| 2 | 0.008178 | 0.01163 | 0.008191 | 0.008245 | 0.008266 | 0.008182 | 0.008164 |
| 3 | 0.008047 | 0.008191 | 0.01169 | 0.008447 | 0.008558 | 0.008538 | 0.008560 |
| 4 | 0.007921 | 0.008245 | 0.008447 | 0.01224 | 0.009054 | 0.009134 | 0.009214 |
| 5 | 0.007815 | 0.008266 | 0.008558 | 0.009054 | 0.01282 | 0.009540 | 0.009662 |
| 6 | 0.007636 | 0.008182 | 0.008538 | 0.009134 | 0.009540 | 0.01316 | 0.009887 |
| 7 | 0.007562 | 0.008164 | 0.008560 | 0.009214 | 0.009662 | 0.009887 | 0.01348 |

**Estimated V Correlation Matrix for ID 1**

| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
|---|---|---|---|---|---|---|---|
| 1 | 1.0000 | 0.6996 | 0.6864 | 0.6605 | 0.6367 | 0.6140 | 0.6008 |

| Estimated V Correlation Matrix for ID 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
| 2 | 0.6996 | 1.0000 | 0.7026 | 0.6912 | 0.6772 | 0.6615 | 0.6521 |
| 3 | 0.6864 | 0.7026 | 1.0000 | 0.7062 | 0.6991 | 0.6883 | 0.6818 |
| 4 | 0.6605 | 0.6912 | 0.7062 | 1.0000 | 0.7230 | 0.7198 | 0.7174 |
| 5 | 0.6367 | 0.6772 | 0.6991 | 0.7230 | 1.0000 | 0.7346 | 0.7351 |
| 6 | 0.6140 | 0.6615 | 0.6883 | 0.7198 | 0.7346 | 1.0000 | 0.7423 |
| 7 | 0.6008 | 0.6521 | 0.6818 | 0.7174 | 0.7351 | 0.7423 | 1.0000 |

**Estimated G matrix is not positive definite.**

| Covariance Parameter Estimates | | | | | |
|---|---|---|---|---|---|
| Cov Parm | Subject | Estimate | Standard Error | Z Value | Pr Z |
| UN(1,1) | ID | 0.06208 | 0.01242 | 5.00 | <.0001 |
| UN(2,1) | ID | -0.02683 | 0.01507 | -1.78 | 0.0750 |
| UN(2,2) | ID | 0.01378 | 0.02922 | 0.47 | 0.3186 |
| UN(3,1) | ID | -0.00829 | 0.006618 | -1.25 | 0.2105 |
| UN(3,2) | ID | 0.004489 | 0.01414 | 0.32 | 0.7509 |
| UN(3,3) | ID | 0.000754 | 0.007514 | 0.10 | 0.4600 |
| Residual | | 0.003425 | 0.000131 | 26.24 | <.0001 |

| Fit Statistics | |
|---|---|
| -2 Res Log Likelihood | -4645.5 |
| AIC (Smaller is Better) | -4631.5 |

| Fit Statistics | |
|---|---|
| AICC (Smaller is Better) | -4631.4 |
| BIC (Smaller is Better) | -4605.6 |

```
proc mixed data = air_pol method=ML;
class ID;
model Log_FEV1 =  Height L_Age / solution;
random intercept Height/type=UN subject=ID g gcorr v vcorr;
run;
```

| Fit Statistics | |
|---|---|
| -2 Log Likelihood | -4664.6 |
| AIC (Smaller is Better) | -4650.6 |
| AICC (Smaller is Better) | -4650.5 |
| BIC (Smaller is Better) | -4624.7 |

```
proc mixed data = air_pol method=ML;;
class ID;
model Log_FEV1 =  Height L_Age L_Age*L_Age/ solution;
random intercept Height_C/type=UN subject=ID g gcorr v vcorr;
run;
```

| Fit Statistics | |
|---|---|
| -2 Log Likelihood | -4689.1 |
| AIC (Smaller is Better) | -4673.1 |
| AICC (Smaller is Better) | -4673.0 |
| BIC (Smaller is Better) | -4643.5 |

```
proc mixed data = air_pol method=ML;
class ID Age_fl;
model Log_FEV1 =  Height Age_fl / solution;
random intercept Height/type=UN subject=ID g gcorr v vcorr;
run;
```

| Fit Statistics | |
|---|---|
| -2 Log Likelihood | -4801.9 |
| AIC (Smaller is Better) | -4765.9 |
| AICC (Smaller is Better) | -4765.5 |
| BIC (Smaller is Better) | -4699.2 |

```
proc mixed data = air_pol method=ML;
class ID Age_fl;
model Log_FEV1 =  Height_C Height_C*Height_C Age_fl/ solution;
random intercept Height_C/type=UN subject=ID g gcorr v vcorr;
run;
```

| Fit Statistics | |
|---|---|
| -2 Log Likelihood | -4803.2 |
| AIC (Smaller is Better) | -4765.2 |
| AICC (Smaller is Better) | -4764.8 |
| BIC (Smaller is Better) | -4694.9 |

```
proc mixed data = air_pol;
class ID Age_fl;
model Log_FEV1 =  Height Age_fl/ solution outp=air_pol_age_pred;
random intercept Height/type=UN subject=ID g gcorr v vcorr;
run;
```

**The Mixed Procedure**

| Model Information | |
|---|---|
| **Data Set** | WORK.AIR_POL |
| **Dependent Variable** | Log_FEV1 |
| **Covariance Structure** | Unstructured |
| **Subject Effect** | ID |
| **Estimation Method** | REML |
| **Residual Variance Method** | Profile |
| **Fixed Effects SE Method** | Model-Based |
| **Degrees of Freedom Method** | Containment |

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **ID** | 299 | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 |
| **Age_fl** | 13 | 6 7 8 9 10 11 12 13 14 15 16 17 18 |

| Dimensions | |
|---|---|
| **Covariance Parameters** | 4 |
| **Columns in X** | 15 |
| **Columns in Z per Subject** | 2 |

| Dimensions | |
|---|---|
| Subjects | 299 |
| Max Obs per Subject | 12 |

| Number of Observations | |
|---|---|
| Number of Observations Read | 1993 |
| Number of Observations Used | 1993 |
| Number of Observations Not Used | 0 |

**Iteration History**

| Iteration | Evaluations | -2 Res Log Like | Criterion |
|---|---|---|---|
| 0 | 1 | -2925.36557288 | |
| 1 | 2 | -4687.50716296 | 0.00004161 |
| 2 | 1 | -4687.68868165 | 0.00000024 |
| 3 | 1 | -4687.68970168 | 0.00000000 |

Convergence criteria met.

**Estimated G Matrix**

| Row | Effect | ID | Col1 | Col2 |
|---|---|---|---|---|
| 1 | Intercept | 1 | 0.07629 | -0.05131 |
| 2 | Height | 1 | -0.05131 | 0.03869 |

**Estimated G Correlation Matrix**

| Row | Effect | ID | Col1 | Col2 |
|---|---|---|---|---|
| 1 | Intercept | 1 | 1.0000 | -0.9445 |
| 2 | Height | 1 | -0.9445 | 1.0000 |

| Estimated V Matrix for ID 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
| 1 | 0.01200 | 0.008465 | 0.008221 | 0.007781 | 0.007488 | 0.007390 | 0.007292 |
| 2 | 0.008465 | 0.01147 | 0.008232 | 0.008071 | 0.007964 | 0.007928 | 0.007892 |
| 3 | 0.008221 | 0.008232 | 0.01138 | 0.008252 | 0.008261 | 0.008264 | 0.008267 |
| 4 | 0.007781 | 0.008071 | 0.008252 | 0.01172 | 0.008796 | 0.008868 | 0.008941 |
| 5 | 0.007488 | 0.007964 | 0.008261 | 0.008796 | 0.01230 | 0.009272 | 0.009391 |
| 6 | 0.007390 | 0.007928 | 0.008264 | 0.008868 | 0.009272 | 0.01255 | 0.009541 |
| 7 | 0.007292 | 0.007892 | 0.008267 | 0.008941 | 0.009391 | 0.009541 | 0.01284 |

| Estimated V Correlation Matrix for ID 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Row | Col1 | Col2 | Col3 | Col4 | Col5 | Col6 | Col7 |
| 1 | 1.0000 | 0.7216 | 0.7033 | 0.6560 | 0.6163 | 0.6021 | 0.5875 |
| 2 | 0.7216 | 1.0000 | 0.7205 | 0.6961 | 0.6706 | 0.6608 | 0.6505 |
| 3 | 0.7033 | 0.7205 | 1.0000 | 0.7143 | 0.6981 | 0.6913 | 0.6838 |
| 4 | 0.6560 | 0.6961 | 0.7143 | 1.0000 | 0.7325 | 0.7311 | 0.7288 |
| 5 | 0.6163 | 0.6706 | 0.6981 | 0.7325 | 1.0000 | 0.7463 | 0.7474 |
| 6 | 0.6021 | 0.6608 | 0.6913 | 0.7311 | 0.7463 | 1.0000 | 0.7516 |
| 7 | 0.5875 | 0.6505 | 0.6838 | 0.7288 | 0.7474 | 0.7516 | 1.0000 |

| Covariance Parameter Estimates | | |
|---|---|---|
| Cov Parm | Subject | Estimate |
| UN(1,1) | ID | 0.07629 |
| UN(2,1) | ID | -0.05131 |

| Covariance Parameter Estimates | | |
|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** |
| **UN(2,2)** | ID | 0.03869 |
| **Residual** | | 0.003146 |

| Fit Statistics | |
|---|---|
| **-2 Res Log Likelihood** | -4687.7 |
| **AIC (Smaller is Better)** | -4679.7 |
| **AICC (Smaller is Better)** | -4679.7 |
| **BIC (Smaller is Better)** | -4664.9 |

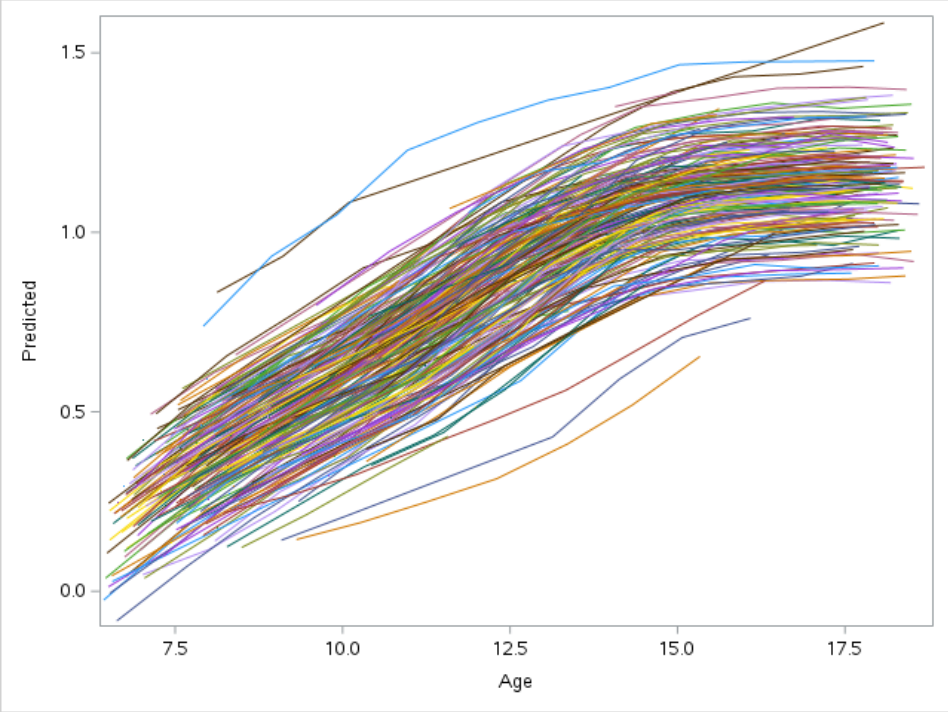
| Null Model Likelihood Ratio Test | | |
|---|---|---|
| **DF** | **Chi-Square** | **Pr > ChiSq** |
| 3 | 1762.32 | <.0001 |

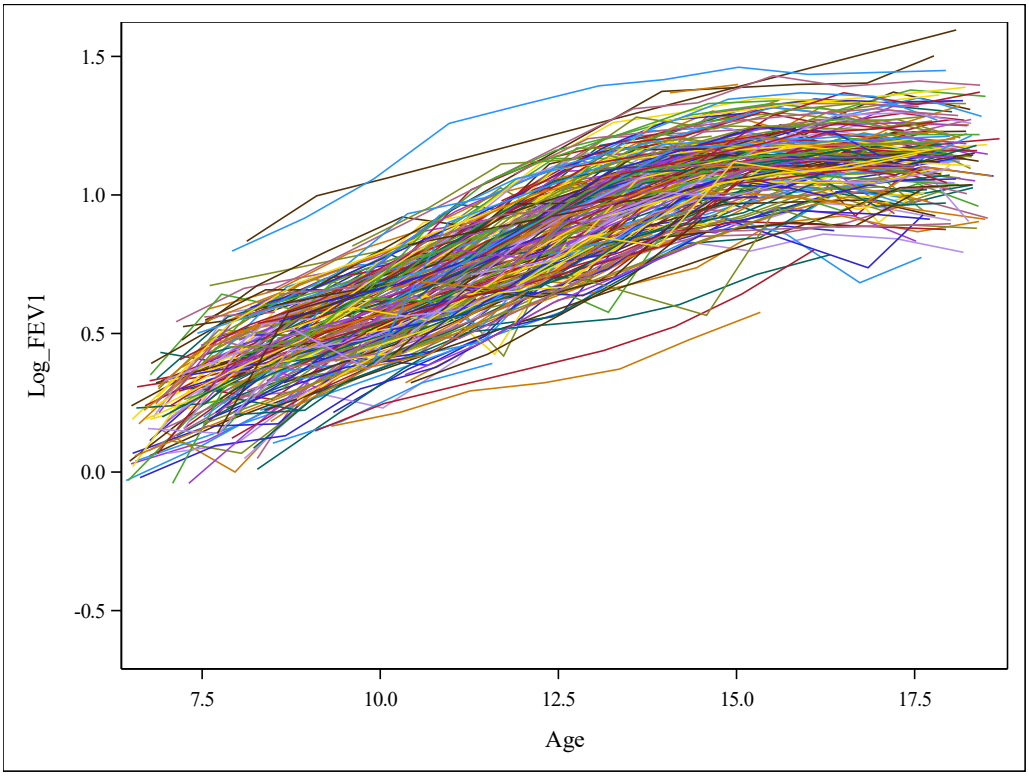
| Solution for Fixed Effects | | | | | | |
|---|---|---|---|---|---|---|
| **Effect** | **Age_fl** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Intercept** | | -1.6180 | 0.08785 | 298 | -18.42 | <.0001 |
| **Height** | | 1.6769 | 0.05377 | 251 | 31.19 | <.0001 |
| **Age_fl** | 6 | -0.2116 | 0.02651 | 1430 | -7.98 | <.0001 |
| **Age_fl** | 7 | -0.1556 | 0.02267 | 1430 | -6.86 | <.0001 |
| **Age_fl** | 8 | -0.1356 | 0.01977 | 1430 | -6.86 | <.0001 |
| **Age_fl** | 9 | -0.1258 | 0.01706 | 1430 | -7.37 | <.0001 |
| **Age_fl** | 10 | -0.1200 | 0.01440 | 1430 | -8.33 | <.0001 |
| **Age_fl** | 11 | -0.1179 | 0.01186 | 1430 | -9.94 | <.0001 |

| Solution for Fixed Effects | | | | | | |
|---|---|---|---|---|---|---|
| **Effect** | **Age_fl** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Age_fl** | 12 | -0.09507 | 0.009837 | 1430 | -9.66 | <.0001 |
| **Age_fl** | 13 | -0.06758 | 0.008884 | 1430 | -7.61 | <.0001 |
| **Age_fl** | 14 | -0.02852 | 0.008516 | 1430 | -3.35 | 0.0008 |
| **Age_fl** | 15 | -0.00407 | 0.008368 | 1430 | -0.49 | 0.6269 |
| **Age_fl** | 16 | 0.003642 | 0.008394 | 1430 | 0.43 | 0.6645 |
| **Age_fl** | 17 | 0.006674 | 0.008410 | 1430 | 0.79 | 0.4276 |
| **Age_fl** | 18 | 0 | . | . | . | . |

| Type 3 Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Height** | 1 | 251 | 972.65 | <.0001 |
| **Age_fl** | 12 | 1430 | 30.47 | <.0001 |

```
Proc SGplot data = air_pol_age_pred;
series x=Age y=pred / group =ID LineAttrs= (pattern=1 );
run;
```


1.5
1.0
0.5
0.0
Predicted
7.5
10.0
12.5
15.0
17.5
Age


1.5
1.0
0.5
0.0
-0.5
Log_FEV1
7.5
10.0
12.5
15.0
17.5
Age

```
Proc SGplot data = air_pol_age_pred;
series x=Height y=pred / group =ID LineAttrs= (pattern=1 );
run;
```