Example 3: Clustered Longitudinal Data for Time within Person within Twin Pair

The data for this example come from the Octogenarian Twin Study of Aging, a longitudinal study (with 5 occasions spanning 8 years) of same-sex twin pairs initially age 79-100. We will be examining change over time in a measure of crystallized intelligence (information test), as well as prediction of that change from a measured of physical functioning (grip strength measured in pounds). These data are already stacked such that one row contains the data for one occasion for one person. The ID variables PairID and TwinID index which twin pair and which person, respectively, and Case is a unique identifier for each person. Time is unbalanced across persons, so the REPEATED statement will not be used (because we have to assume a VC R matrix anyway).

Model 1a: Empty Means, 2-Level Model for Information Test Outcome

Level 1: $Info_{ti} = \beta_{0i} + e_{ti}$
Level 2: $\beta_{0i} = \gamma_{00} + U_{0i}$

This model has 2 variance components: residual at level 1 and random intercept at level 2. It assumes that all people are independent (does not account for twin pair membership).

```
TITLE "SAS Model 1a: Empty Means, 2-Level Model for Information Test Outcome";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info =    / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID*TwinID; RUN;

TITLE "SPSS Model 1a: Empty Means, 2-Level Model for Information Test Outcome".
MIXED info BY PairID TwinID
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  =
  /RANDOM = INTERCEPT | SUBJECT(PairID*TwinID) COVTYPE(UN).

 * STATA Model 1a: Empty Means, 2-Level Model for Information Test Outcome
xtmixed info ,  || Case:  , variance reml covariance(unstructured)
       estat ic, n(594)
       estimates store TwoLevel
```

STATA output:

```
Mixed-effects REML regression                   Number of obs      =      1734
Group variable: Case                            Number of groups   =       594
                                                Obs per group: min =         1
                                                               avg =       2.9
                                                               max =         5
                                                Wald chi2(0)       =         .
Log restricted-likelihood = -6073.7202          Prob > chi2        =         .
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _cons |   25.46294   .4909978    51.86   0.000      24.5006    26.42527
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
Case: Identity               |
                  var(_cons) |   130.5222    8.38369      115.0827    148.0331
-----------------------------+------------------------------------------------
               var(Residual) |   26.66816   1.120232       24.5605    28.95669
------------------------------------------------------------------------------
LR test vs. linear regression: chibar2(01) =  1411.30 Prob >= chibar2 = 0.0000
.         estat ic, n(594)
-----------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+---------------------------------------------------------------
           . |    594           .    -6073.72      3     12153.44     12166.6
-----------------------------------------------------------------------------
               Note:  N=594 used in calculating BIC
```

Calculate the ICC for the proportion of between-person variation in Info:

$$ICC = \frac{130.52}{130.52 + 26.67} = .83$$

This LR test tells us that the random intercept variance is significantly greater than 0,

Model 1b: Empty Means, 3-Level Model for Information Test Outcome

Level 1: $Info_{tij} = \beta_{0ij} + e_{tij}$
Level 2: $\beta_{0ij} = \delta_{00j} + U_{0ij}$
Level 3: $\delta_{00j} = \gamma_{000} + V_{00j}$

This model now has 3 variance components: residual at level-1, random intercept at level 2, and random intercept at level 3. It now allows a correlation between people from the same twin pair.

```
TITLE "SAS Model 1b: Empty Means, 3-Level Model for Information Test Outcome";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info =    / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID;           * Level 3;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID*TwinID;    * Level 2; RUN;

TITLE "SPSS Model 1b: Empty Means, 3-Level Model for Information Test Outcome".
MIXED info BY PairID TwinID
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  =
  /RANDOM = INTERCEPT | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT | SUBJECT(PairID*TwinID) COVTYPE(UN).

 * STATA Model 1b: Empty Means, 3-Level Model for Information Test Outcome
xtmixed info ,  || PairID:  ,   covariance(unstructured) ///
       || Case: , variance reml covariance(unstructured)
       estat ic, n(337)
       estimates store ThreeLevel
       lrtest ThreeLevel TwoLevel
```

STATA output:

```
Mixed-effects REML regression                   Number of obs      =      1734
------------------------------------------------------------
                |   No. of       Observations per Group
 Group Variable |   Groups    Minimum    Average    Maximum
----------------+-------------------------------------------
         PairID |      337          1        5.1         10
           Case |      594          1        2.9          5
------------------------------------------------------------
                                                Wald chi2(0)       =         .
Log restricted-likelihood = -6022.9702          Prob > chi2        =         .
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _cons |   25.21018   .5962409    42.28   0.000     24.04157    26.37879
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   83.73498   9.817706      66.54352    105.3678  → level-3 between-pair
-----------------------------+------------------------------------------------
Case: Identity    var(_cons) |   47.33563   5.399659      37.85212    59.19517  → level-2 within-pair
-----------------------------+------------------------------------------------
              var(Residual) |   26.75497   1.126957      24.63489     29.0575  → level-1 within-person
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(2) =  1512.80   Prob > chi2 = 0.0000
Note: LR test is conservative and provided only for reference.
.         estat ic, n(337)
-----------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+---------------------------------------------------------------
           . |    337           .    -6022.97      4     12053.94    12069.22
-----------------------------------------------------------------------------
              Note:  N=337 used in calculating BIC
```

```
.         estimates store ThreeLevel
.         lrtest ThreeLevel TwoLevel
```

Is the 3-level model a better fit than the 2-level model?
Yes, −2ΔLL(1) = 101.5, p < .001

```
Likelihood-ratio test                                 LR chi2(1)  =     101.50
(Assumption: TwoLevel nested in ThreeLevel)           Prob > chi2 =     0.0000

Note: The reported degrees of freedom assumes the null hypothesis is not on the boundary of the parameter
space.  If this is not true, then the reported test is conservative. Note: LR tests based on REML are valid
only when the fixed-effects specification is identical for both models.
```

Proportion variance at each level:

Level 1 (time) = 26.75 / 157.83 = .17
Level 2 (person) = 47.34 / 157.83 = .30
Level 3 (pair) = 83.73 / 157.83 = .53

ICC for time within person & pair =
83.73 + 47.34 / (83.73 + 47.34 + 26.75) = .83

ICC for person within pair = 83.72 / (83.72 + 47.33) = .64
This ICC = .64 is significantly greater than 0 via −2ΔLL for 3- vs. 2-level.

Now let's do the same thing for our two time-varying predictors: age and grip strength.

Age Model: Empty Means, 3-Level Model for Age Predictor

```
TITLE "SAS Age Model: Empty Means, 3-Level Model for Age Predictor";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL age =   / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID;           * Level 3;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID*TwinID;    * Level 2; RUN;

TITLE "SPSS Age Model: Empty Means, 3-Level Model for Age Predictor".
MIXED age BY PairID TwinID
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  =
  /RANDOM = INTERCEPT | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT | SUBJECT(PairID*TwinID) COVTYPE(UN).

 * STATA Age Model: Empty Means, 3-Level Model for Age Predictor
xtmixed age ,  || PairID:  ,   covariance(unstructured) ///
       || Case: , variance reml covariance(unstructured)
```

STATA output:

```
------------------------------------------------------------------------------
         age |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _cons |   85.96476   .1585134   542.32   0.000     85.65408    86.27544
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   6.553374   .6752503      5.354986    8.019948 level-3 between-pair = 47%
-----------------------------+------------------------------------------------
Case: Identity    var(_cons) |   2.84e-23   5.82e-23      5.09e-25    1.58e-21 level-2 within-pair = 0%
-----------------------------+------------------------------------------------
               var(Residual) |   7.466046   .2842018      6.929293    8.044377 level-1 within-person = 53%
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(2) =   459.38   Prob > chi2 = 0.0000
```

Because there is no age variance at level 2, age will be a predictor at levels 1 and 3 only.

Grip Strength Model: Empty Means, 3-Level Model for Grip Strength Predictor

```
TITLE "SAS Grip Model: Empty Means, 3-Level Model for Grip Strength Predictor";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL gripp =   / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID;           * Level 3;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID*TwinID;    * Level 2; RUN;

TITLE "SPSS Grip Model: Empty Means, 3-Level Model for Grip Strength Predictor".
MIXED gripp BY PairID TwinID
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  =
  /RANDOM = INTERCEPT | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT | SUBJECT(PairID*TwinID) COVTYPE(UN).

 * STATA Grip Model: Empty Means, 3-Level Model for Grip Strength Predictor
xtmixed gripp ,  || PairID:  ,   covariance(unstructured) ///
       || Case: , variance reml covariance(unstructured)
```

STATA output:

```
------------------------------------------------------------------------------
       gripp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       _cons |    8.06599   .1268694    63.58   0.000     7.817331     8.31465
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   3.085847   .4673646      2.293276    4.152336 level-3 between-pair = 36%
-----------------------------+------------------------------------------------
Case: Identity    var(_cons) |   2.552534   .3436612      1.960513    3.323329 level-2 within-pair = 29%
-----------------------------+------------------------------------------------
              var(Residual) |   3.049563   .1271551      2.810255    3.309249 level-1 within-person = 35%
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(2) =   795.50   Prob > chi2 = 0.0000
```

Because there is grip strength variance at all levels, grip strength will be a predictor at all levels.

We now need to create our predictor variables, including a mean of grip strength at the pair and person levels. We then code time as “time-in-study” and use baseline age as between-pair age. This gives us a convenient demarcation of age at baseline as the cross-sectional effect of age, and time-in-study as the longitudinal effect of age.

SAS Data Manipulation:

```
* Importing data into work library and creating person mean gripp for level-2;
DATA work.octodata; SET octo.octodata;
       PMgripp = MEAN(OF gripp1-gripp5);
       LABEL PMgripp= "PMgripp: Person Mean Gripp"; RUN;

* Getting twin pair means for grip strength to use at level-3;
PROC SORT DATA=work.octodata; BY PairID TwinID Wave; run;
PROC MEANS NOPRINT DATA=work.octodata; BY PairID; VAR PMgripp;
       OUTPUT OUT=PairMeans MEAN(PMgripp) = FMgripp; RUN;

* Merging PairMeans with datafile and centering predictors;
DATA work.octodata; MERGE work.octodata work.PairMeans; BY PairID;
       LABEL FMgripp= "FMgripp: Family Mean Gripp";

*** Age Variables ***;
       * Centering age at time 1 at 85 to use at level-3;
              BFage85 = agew1 - 85; LABEL BFage85= "BFage85: Age at Time1 (0=85)";
       * Within-person centering age at level-1 (like PERSON MEAN CENTERING);
              time = age - agew1;   LABEL time="time: Time Since Entry (0= Age Wave 1)";
```

```
*** Grip Strength Variables ***;
       * Centering family mean gripp at 9 to use at level-3;
              BFgripp9 = FMgripp - 9;
       * Centering person mean gripp at 9 to use at level-2;
              BPgripp9 = PMgripp - 9;          * GRAND MEAN CENTERING;
              WFgripp  = PMgripp - FMgripp;    * PERSON MEAN CENTERING;
       * Centering time-varying gripp to use at level-1;
              TVgripp9 = gripp - 9;            * GRAND MEAN CENTERING;
              WPgripp  = gripp - PMgripp;      * PERSON MEAN CENTERING;
       LABEL BFgripp9=  "BFgripp9:  Between-Family Mean Grip Strength in Pounds (0=9)"
              BPgripp9=  "BPgripp9: Between-Person Mean Grip Strength in Pounds (0=9)"
              WFgripp=   "WFgripp:  Within-Family Deviation from Mean Grip Strength in Pounds"
              TVgripp9=  "TVgripp9: Time-Varying Grip Strength in Pounds (0=9)"
              WPgripp=   "WPgripp:  Within-Person Deviation from Mean Grip Strength in Pounds";

* Selecting only cases with complete data;
       IF NMISS(agew1, age, FMgripp, PMgripp, gripp, info)>0 THEN DELETE; RUN;
```

SPSS Data Manipulation:

```
SORT CASES BY PairID TwinID Wave.
* Getting person gripp means to use as level-2 predictor.
COMPUTE PMgripp = MEAN(gripp1 TO gripp5).
EXECUTE.
* Getting pair gripp means to use as level-3 predictor.
AGGREGATE /OUTFILE=* MODE=ADDVARIABLES /PRESORTED /BREAK = PairID /FMgripp = MEAN(PMgripp).
VARIABLE LABELS FMgripp "FMgripp: Family Mean Gripp" PMgripp "PMgripp: Person Mean Gripp".

*** Age Variables ***.
       * Centering age at time 1 at 85 to use at level-3.
              COMPUTE BFage85 = agew1 - 85.
       * Within-person centering age at level-1 (like PERSON MEAN CENTERING).
              COMPUTE time = age - agew1.
              VARIABLE LABELS BFage85 "BFage85: Age at Time1 (0=85)"
                              time    "time: Time Since Entry (0= Age Wave 1)".

*** Grip Strength Variables ***.
       * Centering family mean gripp at 9 to use at level-3.
              COMPUTE BFgripp9 = FMgripp - 9.
       * Centering person mean gripp at 9 to use at level-2.
              COMPUTE BPgripp9 = PMgripp - 9.
              COMPUTE WFgripp  = PMgripp - FMgripp.
       * Centering time-varying gripp to use at level-1.
              COMPUTE TVgripp9 = gripp - 9.
              COMPUTE WPgripp  = gripp - PMgripp.
       VARIABLE LABELS
              BFgripp9 "BFgripp9: Between-Family Mean Grip Strength in Pounds (0=9)"
              BPgripp9 "BPgripp9: Between-Person Mean Grip Strength in Pounds (0=9)"
              WFgripp  "WFgripp:  Within-Family Deviation from Mean Grip Strength in Pounds"
              TVgripp9 "TVgripp9: Time-Varying Grip Strength in Pounds (0=9)"
              WPgripp  "WPgripp:  Within-Person Deviation from Mean Grip Strength in Pounds".

* Selecting only complete cases.
       SELECT IF (NMISS(agew1, age, FMgripp, PMgripp, gripp, info)=0).
       EXECUTE.
```

STATA Data Manipulation:

```
 * Creating person mean gripp for level-2
egen PMgripp = rmean(GRIPP1-GRIPP5)
label variable PMgripp "PMgripp: Person Mean Gripp"
 * Creating family mean gripp for level-3
egen FMgripp = mean(PMgripp), by(PairID)
label variable FMgripp "FMgripp: Family Mean Gripp"
```

```
 * Age variables
 * centering age at time 1 at 85 to use at level-3
gen BFage85 = agew1 - 85
label variable BFage85 "BFage85: Age at Time1 (0=85)"
 * within person centering age at level-1 (like PERSON MEAN CENTERING)
gen time = age - agew1
label variable time "time: Time since entry (0= Age Wave 1)"

 * Grip Strength Variables
 * centering family mean gripp at 9 use at level-3
gen BFgripp9 = FMgripp - 9
 * centering person mean gripp at 9 to use at level-2
gen BPgripp9 = PMgripp - 9          // GRAND MEAN CENTERING
gen WFgripp  = PMgripp - FMgripp    // PERSON MEAN CENTERING
 * centering time-varying gripp to use at level-1
gen TVgripp9 = gripp - 9            // GRAND MEAN CENTERING
gen WPgripp  = gripp - PMgripp      // PERSON MEAN CENTERING

label variable BFgripp9 "BFgripp9: Between-Family Mean Grip Strength in Pounds (0=9)"
label variable BPgripp9 "BPgripp9: Between-Person mean gripp strength in pounds (0=9)"
label variable WFgripp  "WFgripp:  Within-Family deviation from mean grip strength in Pounds"
label variable TVgripp9 "TVgripp9: Time-Varying Grip Strength in Pounds (0=9)"
label variable WPgripp  "WPgripp:  Within-Person Deviation from Mean Grip Strength in Pounds"

* Selecting only cases with complete data
egen nummiss = rowmiss(agew1 age FMgripp PMgripp gripp info)
drop if nummiss>0
```

Model 2a: Fixed Quadratic, Random Intercepts at Levels 2 and 3

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right)^2 + e_{tij}$

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + U_{0ij}$

Linear Time: $\beta_{1ij} = \delta_{10j}$

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_j - 85\right) + V_{00j}$

Linear Time: $\delta_{10j} = \gamma_{100}$

Quadratic Time: $\delta_{20j} = \gamma_{200}$

```
TITLE "SAS Model 2a: Fixed Quadratic, Random Intercept for Pair and Twin";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID;           * Level 3;
       RANDOM INTERCEPT / TYPE=UN SUBJECT=PairID*TwinID;    * Level 2; RUN;

TITLE "SPSS Model 2a: Fixed Quadratic, Random Intercept for Pair and Twin".
MIXED info BY PairID TwinID WITH BFage85 time
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time
  /RANDOM = INTERCEPT | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT | SUBJECT(PairID*TwinID) COVTYPE(UN).
* STATA Model 2a: Fixed Quadratic, Random Intercepts at Levels 2 and 3
xtmixed info c.BFage85 c.time c.time#c.time , || PairID: , covariance(unstructured) ///
       || Case:  , variance reml covariance(unstructured)
       estat ic, n(337)
       estimates store FixQuad
```

STATA output:

```
                                                Wald chi2(3)      =     195.45
Log restricted-likelihood = -5939.0225          Prob > chi2       =     0.0000
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     BFage85 |  -.8073689   .1942406    -4.16   0.000    -1.188074   -.4266643
        time |  -.2350914   .1456677    -1.61   0.107    -.5205948    .050412
c.time#c.time |  -.0555854   .0187153    -2.97   0.003    -.0922667   -.018904
       _cons |   25.10103   .6834791    36.73   0.000     23.76144    26.44062
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   79.53662   9.694711       62.6346    100.9997
-----------------------------+------------------------------------------------
Case: Identity    var(_cons) |    52.4136    5.67978      42.38419    64.81628
-----------------------------+------------------------------------------------
             var(Residual) |   22.77218   .9601037      20.96606    24.73389
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(2) =  1636.90   Prob > chi2 = 0.0000
------------------------------------------------------------------------------
      Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
------------+-----------------------------------------------------------------
          . |    337           .   -5939.023      7     11892.05    11918.79
```

This model has 3 variance components: residual at level-1, random intercept at level-2, and random intercept at level-3. It now also has 3 new fixed effects: BFage85, time, and time^2.

We do not compare REML deviances because these models differ in fixed effects. Instead, we use their p-values. This is our new unconditional growth model baseline, as obtained from testing sequential models not shown here.

Model 2b: Fixed Quadratic, Random Linear Slope at Level 2

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right)^2 + e_{tij}$

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + U_{0ij}$

Linear Time: $\beta_{1ij} = \delta_{10j} + U_{1ij}$

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_j - 85\right) + V_{00j}$

Linear Time: $\delta_{10j} = \gamma_{100}$

Quadratic Time: $\delta_{20j} = \gamma_{200}$

```
TITLE "SAS Model 2b: Add Random Linear Slope for Twin";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time  / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT      / TYPE=UN SUBJECT=PairID;             * Level 3;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID*TwinID;      * Level 2; RUN;

TITLE "SPSS Model 2b: Add Random Linear Slope for Twin".
MIXED info BY PairID TwinID WITH BFage85 time
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time
  /RANDOM = INTERCEPT       | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT time | SUBJECT(PairID*TwinID) COVTYPE(UN).

* STATA Model 2b: Add Random Linear Slope for Twin
xtmixed info c.BFage85 c.time c.time#c.time , || PairID: , covariance(unstructured) ///
       || Case: time , variance reml covariance(unstructured)
       estat ic, n(337)
       estimates store RandLin2
       lrtest RandLin2 FixQuad
```

STATA output:

```
                                                Wald chi2(3)       =    188.20
Log restricted-likelihood = -5872.9993          Prob > chi2        =    0.0000
------------------------------------------------------------------------------
         info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
      BFage85 |  -.7307761   .1909202    -3.83   0.000    -1.104973   -.3565793
         time |  -.1454705    .132939    -1.09   0.274    -.4060262    .1150853
c.time#c.time |  -.1021417   .0165422    -6.17   0.000    -.1345639   -.0697195
        _cons |   25.27722   .6626819    38.14   0.000     23.97839    26.57605
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   80.10376   9.410732      63.62858    100.8448 → level-3 intercept var
-----------------------------+------------------------------------------------
Case: Unstructured           |
                   var(time) |   1.178443   .1805631      .8727425    1.591224 → level-2 linear var
                  var(_cons) |   44.31214   5.257737      35.11767    55.91389 → level-2 intercept var
              cov(time,_cons) |   1.622178   .7900245      .0737584    3.170598 → level-2 int-linear cov
-----------------------------+------------------------------------------------
                var(Residual) |   15.12274   .8324702      13.57607    16.84563 → level-1 residual var
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(4) =  1768.94   Prob > chi2 = 0.0000
------------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+----------------------------------------------------------------
           . |    337           .   -5872.999      9        11764    11798.38
------------------------------------------------------------------------------

.         estimates store RandLin2

.         lrtest RandLin2 FixQuad

Likelihood-ratio test                                 LR chi2(2)  =    132.05
(Assumption: FixQuad nested in RandLin2)              Prob > chi2 =    0.0000

Note: The reported degrees of freedom assumes the null hypothesis is not on the boundary of the parameter
space.  If this is not true, then the reported test is conservative. Note: LR tests based on REML are valid
only when the fixed-effects specification is identical for both models.
```

This model has 2 new variance components at level 2: random linear slope and intercept-slope covariance.
Do we need the random linear slope for twin?
Yes, $-2\Delta LL(2) = 132$, $p < .001$

Model 2c: Fixed Quadratic, Random Linear Slope at Levels 2 and 3

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_{j}\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_{j}\right)^2 + e_{tij}$

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + U_{0ij}$

Linear Time: $\beta_{1ij} = \delta_{10j} + U_{1ij}$

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_{j} - 85\right) + V_{00j}$

Linear Time: $\delta_{10j} = \gamma_{100} + V_{10j}$

Quadratic Time: $\delta_{20j} = \gamma_{200}$

```
TITLE "SAS Model 2c: Add Random Linear Slope for Pair";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID;          * Level 3;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID*TwinID;   * Level 2; RUN;

TITLE "SPSS Model 2c: Add Random Linear Slope for Pair".
MIXED info BY PairID TwinID WITH BFage85 time
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time
  /RANDOM = INTERCEPT time | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT time | SUBJECT(PairID*TwinID) COVTYPE(UN).
* STATA Model 2c: Add Random Linear Slope for Pair
xtmixed info c.BFage85 c.time c.time#c.time , || PairID: time, covariance(unstructured) ///
       || Case: time , variance reml covariance(unstructured)
       estat ic, n(337)
       estimates store RandLin23
       lrtest RandLin23 RandLin2
```

STATA output:

```
                                                Wald chi2(3)       =    182.94
Log restricted-likelihood = -5872.6076          Prob > chi2        =    0.0000
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      BFage85 |  -.7438709    .190867    -3.90   0.000    -1.117963   -.3697784
        time |  -.1429383    .133292    -1.07   0.284    -.4041859    .1183093
c.time#c.time |  -.1016908   .0165408    -6.15   0.000    -.1341103   -.0692713
       _cons |   25.25502   .6639108    38.04   0.000     23.95378    26.55626
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Unstructured         |
                   var(time) |   .0640187   .1696797       .000355     11.5449 → level-3 linear var
                  var(_cons) |   80.86105   9.503706      64.22388    101.8081 → level-3 intercept var
              cov(time,_cons) |  -.7329904   .9257944     -2.547514    1.081533 → level-3 int-linear cov
-----------------------------+------------------------------------------------
Case: Unstructured           |
                   var(time) |   1.116498   .2415957      .7305816    1.706266 → level-2 linear var
                  var(_cons) |   44.00753    5.22105      34.87711    55.52819 → level-2 intercept var
              cov(time,_cons) |   1.957119   .8826687      .2271198    3.687117 → level-2 int-linear cov
-----------------------------+------------------------------------------------
               var(Residual) |   15.11455   .8311075      13.57031     16.8345 → level-1 residual var
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(6) =  1769.73   Prob > chi2 = 0.0000
------------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+----------------------------------------------------------------
           . |    337           .   -5872.608     11     11767.22    11809.24
.         estimates store RandLin23

.         lrtest RandLin23 RandLin2

Likelihood-ratio test                                 LR chi2(2)  =      0.78
(Assumption: RandLin2 nested in RandLin23)            Prob > chi2 =    0.6759
```

This model has 2 new variance components at level 3: random linear slope and intercept-slope covariance. **Do we need the random linear slope for pair, too?** *No, −2ΔLL(2) = 0.8, p = .67*

ICC of person within pair:

For Intercepts = 80.86 / (80.86 + 44.01) = .65

For Slopes = 0.06 / (0.06 + 1.12) = .05 (≈ 0)

TWO EQUIVALENT MODELS: PERSON-MEAN-CENTERING VS. GRAND-MEAN-CENTERING

Model 3a: Separate Effects of Grip Strength at Each Level via Person-Mean-Centering

```
TITLE "SAS Model 3a: Grip Strength at each level via PERSON MEAN CENTERING";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time WPgripp WFgripp BFgripp9
                    / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT      / TYPE=UN SUBJECT=PairID;             * Level 3;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID*TwinID;      * Level 2;
       ESTIMATE "Level-2 Contextual Effect" WFgripp  1 WPgripp -1;
       ESTIMATE "Level-3 Contextual Effect" BFgripp9 1 WFgripp -1; RUN;

TITLE "SPSS Model 3a: Grip Strength at each level via PERSON MEAN CENTERING".
MIXED info BY PairID TwinID WITH BFage85 time WPgripp WFgripp BFgripp9
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time WPgripp WFgripp BFgripp9
  /RANDOM = INTERCEPT      | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT time | SUBJECT(PairID*TwinID) COVTYPE(UN)
  /TEST = "Level-2 Contextual Effect" WFgripp  1 WPgripp -1
  /TEST = "Level-3 Contextual Effect" BFgripp9 1 WFgripp -1.
* STATA Model 3a: Grip Strength at each level via PERSON MEAN CENTERING
xtmixed info c.BFage85 c.time c.time#c.time c.WPgripp c.WFgripp c.BFgripp9 , ///
    || PairID: , covariance(unstructured) || Case: time, variance reml covariance(unstructured)
       estat ic, n(337)
       lincom 1*c.WFgripp  - 1*c.WPgripp       // Level-2 Contextual Effect
       lincom 1*c.BFgripp9 - 1*c.WFgripp       // Level-3 Contextual Effect
```

Model 3b: Testing 3-Level Convergence of Grip Strength Effects via Grand-Mean-Centering

```
TITLE "SAS Model 3b: Grip Strength Convergence across levels via GRAND MEAN CENTERING";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time TVgripp9 BPgripp9 BFgripp9
                    / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT      / TYPE=UN SUBJECT=PairID;             * Level 3;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID*TwinID;      * Level 2;
       ESTIMATE "Level-2 Within-Family Effect" TVgripp9 1 BPgripp9 1;
       ESTIMATE "Level-3 Between-Pair  Effect" TVgripp9 1 BPgripp9 1 BFgripp9 1; RUN;

TITLE "SPSS Model 3b: Grip Strength Convergence across levels via GRAND MEAN CENTERING".
MIXED info BY PairID TwinID WITH BFage85 time TVgripp9 BPgripp9 BFgripp9
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time TVgripp9 BPgripp9 BFgripp9
  /RANDOM = INTERCEPT      | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT time | SUBJECT(PairID*TwinID) COVTYPE(UN)
  /TEST = "Level-2 Within-Family Effect" TVgripp9 1 BPgripp9 1
  /TEST = "Level-3 Between-Pair  Effect" TVgripp9 1 BPgripp9 1 BFgripp9 1.

* STATA Model 3b: Grip Strength Convergence across levels via GRAND MEAN CENTERING
xtmixed info c.BFage85 c.time c.time#c.time c.TVgripp9 c.BPgripp9 c.BFgripp9 , ///
    || PairID: , covariance(unstructured) || Case: time, variance reml covariance(unstructured)
       estat ic, n(337)
       lincom 1*c.TVgripp9 + 1*c.BPgripp9                    // Level-2 Within-Family Effect
       lincom 1*c.TVgripp9 + 1*c.BPgripp9 + 1*c.BFgripp9     // Level-3 Between-Pair Effect
```

STATA output:

```
                                                Wald chi2(6)       =    270.77
Log restricted-likelihood = -5838.9589          Prob > chi2        =    0.0000
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   71.39084   8.596088      56.38327    90.39297
-----------------------------+------------------------------------------------
Case: Unstructured           |
                   var(time) |   .9945399   .1647409      .7188274    1.376004
                  var(_cons) |   41.90059   5.043539      33.09495    53.04917
              cov(time,_cons) |   1.224168   .7247081     -.1962339     2.64457
-----------------------------+------------------------------------------------
                var(Residual) |   15.31228   .8413071      13.74903    17.05327
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(4) =  1700.54   Prob > chi2 = 0.0000
------------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC          BIC
-------------+----------------------------------------------------------------
           . |    337           .   -5838.959     12     11701.92     11747.76
------------------------------------------------------------------------------
```

Because the models we will examine for grip strength are equivalent, the variance components and fit statistics are the same for both.

Model 3a: Separate Effects of Grip Strength at Each Level via Person-Mean-Centering

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right)^2 + \beta_{3ij}\left(\text{Grip}_{tij} - \overline{\text{Grip}}_{ij}\right) + e_{tij}$

Within-person grip (WPgripp)

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + \delta_{01j}\left(\overline{\text{Grip}}_{ij} - \overline{\text{Grip}}_j\right) + U_{0ij}$

Within-family grip (WFgripp)

Linear Time: $\beta_{1ij} = \delta_{10j} + U_{1ij}$

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Within-Person Grip: $\beta_{3ij} = \delta_{30j}$

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_j - 85\right) + \gamma_{002}\left(\overline{\text{Grip}}_j - 9\right) + V_{00j}$

Between-family grip (BFgripp9)

Linear Time: $\delta_{10j} = \gamma_{100}$

Quadratic Time: $\delta_{20j} = \gamma_{200}$

Within-Person Grip: $\delta_{30j} = \gamma_{300}$

Within-Family Grip: $\delta_{01j} = \gamma_{010}$

```
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      BFage85 |  -.3463256   .1921102    -1.80   0.071    -.7228547    .0302034
        time |   .0884511   .1386187     0.64   0.523    -.1832365    .3601387
c.time#c.time |  -.1010033   .0165328    -6.11   0.000     -.133407   -.0685995
      WPgripp |   .5031221   .0979629     5.14   0.000     .3111184    .6951259 level-1, total within-person
      WFgripp |   .9143609   .2251347     4.06   0.000     .4731049    1.355617 level-2, total within-family
     BFgripp9 |   1.511445   .2463971     6.13   0.000     1.028515    1.994374 level-3, total between-family
        _cons |   27.04317   .7528849    35.92   0.000     25.56754     28.5188
------------------------------------------------------------------------------
.         lincom 1*c.WFgripp  - 1*c.WPgripp       // Level-2 Contextual Effect
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .4112388    .241575     1.70   0.089    -.0622395    .8847171
------------------------------------------------------------------------------
.         lincom 1*c.BFgripp9 - 1*c.WFgripp       // Level-3 Contextual Effect
------------------------------------------------------------------------------
```

```
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .5970839   .3275152     1.82   0.068     -.044834    1.239002
------------------------------------------------------------------------------
```

Model 3b: Testing 3-Level Convergence of Grip Strength Effects via Grand-Mean-Centering

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_j\right)^2 + \beta_{3ij}\left(\text{Grip}_{tij} - 9\right) + e_{tij}$

Within-person grip (TVgripp9)

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + \delta_{01j}\left(\overline{\text{Grip}}_{ij} - 9\right) + U_{0ij}$

Linear Time: $\beta_{1ij} = \delta_{10j} + U_{1ij}$

Contextual between-person grip (BPgripp9)

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Within-Person Grip: $\beta_{3ij} = \delta_{30j}$

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_j - 85\right) + \gamma_{002}\left(\overline{\text{Grip}}_j - 9\right) + V_{00j}$

Linear Time: $\delta_{10j} = \gamma_{100}$

Contextual between-family grip (BFgripp9)

Quadratic Time: $\delta_{20j} = \gamma_{200}$

Within-Person Grip: $\delta_{30j} = \gamma_{300}$

Within-Family Grip: $\delta_{01j} = \gamma_{010}$

```
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     BFage85 |  -.3463256   .1921102    -1.80   0.071    -.7228547    .0302034
        time |   .0884511   .1386187     0.64   0.523    -.1832365    .3601387
c.time#c.time |  -.1010033   .0165328    -6.11   0.000     -.133407   -.0685995
    TVgripp9 |   .5031221   .0979629     5.14   0.000     .3111184    .6951259 level-1, total within-person
    BPgripp9 |   .4112388    .241575     1.70   0.089    -.0622395     .884717 level-1 = level-2 effect?
    BFgripp9 |   .5970839   .3275152     1.82   0.068     -.044834    1.239002 level-2 = level-3 effect?
       _cons |   27.04317   .7528849    35.92   0.000     25.56754     28.5188
------------------------------------------------------------------------------
. lincom 1*c.TVgripp9 + 1*c.BPgripp9          // Level-2 Within-Family Level 2 Effect
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .9143609   .2251347     4.06   0.000     .4731049    1.355617
------------------------------------------------------------------------------
. lincom 1*c.TVgripp9 + 1*c.BPgripp9 + 1*c.BFgripp9   // Level-3 Between-Pair, Level 3 Effect
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   1.511445   .2463971     6.13   0.000     1.028515    1.994374
------------------------------------------------------------------------------
```

It appears that although there is a significant positive effect of grip strength at each level, those effects may not be significantly different in magnitude. Accordingly, let's simplify the model by removing the contextual effect at level 3, such that the level-2 and level-3 effects of grip strength are assumed to be the same.

Model 3c: Separate Effects of Grip Strength at Level 1 and Level-2&3 via Person-Mean-Centering

```
TITLE "SAS Model 3c: Grip Strength at Level 1 and Level 2&3 via PERSON MEAN CENTERING";
PROC MIXED DATA=work.octodata NOCLPRINT NOITPRINT COVTEST NAMELEN=100 METHOD=REML;
       CLASS PairID TwinID;
       MODEL info = BFage85 time time*time WPgripp BPgripp9 / SOLUTION DDFM=Satterthwaite;
       RANDOM INTERCEPT      / TYPE=UN SUBJECT=PairID;                    * Level 3;
       RANDOM INTERCEPT time / TYPE=UN SUBJECT=PairID*TwinID;             * Level 2;
       ESTIMATE "Level-2&3 Contextual Effect" BFgripp9 1 WPgripp -1; RUN;

TITLE "SPSS Model 3c: Grip Strength at Level 1 and Level 2&3 via PERSON MEAN CENTERING".
MIXED info BY PairID TwinID WITH BFage85 time WPgripp BPgripp9
  /METHOD = REML
  /PRINT  = SOLUTION TESTCOV
  /FIXED  = BFage85 time time*time WPgripp BPgripp9
  /RANDOM = INTERCEPT      | SUBJECT(PairID) COVTYPE(UN)
  /RANDOM = INTERCEPT time | SUBJECT(PairID*TwinID) COVTYPE(UN)
  /TEST = "Level-2&3 Contextual Effect" BPgripp9 1 WPgripp -1.

* STATA Model 3c: Grip Strength at Level 1 and Level 2&3 via PERSON MEAN CENTERING
xtmixed info c.BFage85 c.time c.time#c.time c.WPgripp c.BPgripp9 , ///
    || PairID: , covariance(unstructured) || Case: time, variance reml covariance(unstructured)
       estat ic, n(337)
       lincom 1*c.BPgripp9 - 1*c.WPgripp       // Level-2&3 Contextual Effect
```

Level 1: $\text{Info}_{tij} = \beta_{0ij} + \beta_{1ij}\left(\text{Age}_{tij} - \text{PairAge1}_{j}\right) + \beta_{2ij}\left(\text{Age}_{tij} - \text{PairAge1}_{j}\right)^2 + \beta_{3ij}\left(\text{Grip}_{tij} - \overline{\text{Grip}}_{ij}\right) + e_{tij}$

Level 2:

Intercept: $\beta_{0ij} = \delta_{00j} + \delta_{01j}\left(\overline{\text{Grip}}_{ij} - 9\right) + U_{0ij}$

Linear Time: $\beta_{1ij} = \delta_{10j} + U_{1ij}$

Quadratic Time: $\beta_{2ij} = \delta_{20j}$

Within-Person Grip: $\beta_{3ij} = \delta_{30j}$

Within-person grip (WPgripp)

Between-person grip (BPgripp9)

Level 3:

Intercept: $\delta_{00j} = \gamma_{000} + \gamma_{001}\left(\text{PairAge1}_{j} - 85\right) + V_{00j}$

Linear Time: $\delta_{10j} = \gamma_{100}$

Quadratic Time: $\delta_{20j} = \gamma_{200}$

Within-Person Grip: $\delta_{30j} = \gamma_{300}$

Within-Family Grip: $\delta_{01j} = \gamma_{010}$

STATA output:

```
                                                Wald chi2(5)       =    267.14
Log restricted-likelihood = -5840.4202          Prob > chi2        =    0.0000
------------------------------------------------------------------------------
         info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
      BFage85 |  -.4275427   .1874185    -2.28   0.023    -.7948762   -.0602091
         time |   .0904993   .1386117     0.65   0.514    -.1811746    .3621732
c.time#c.time |  -.1011004   .0165312    -6.12   0.000     -.133501   -.0686997
      WPgripp |   .5071004    .097934     5.18   0.000     .3151532    .6990476
     BPgripp9 |   1.184309   .1695658     6.98   0.000     .8519664    1.516652
        _cons |   26.47672    .687956    38.49   0.000     25.12835    27.82508
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
PairID: Identity  var(_cons) |   71.96326   8.654375      56.85183    91.09136
-----------------------------+------------------------------------------------
Case: Unstructured           |
                   var(time) |   .9952698   .1647394      .7195284    1.376682
                  var(_cons) |   41.97828   5.046668      33.16595    53.13209
              cov(time,_cons) |   1.234527   .7220033      -.180573    2.649628
-----------------------------+------------------------------------------------
                var(Residual) |    15.3081   .8408553      13.74567    17.04813
------------------------------------------------------------------------------
LR test vs. linear regression:       chi2(4) =  1705.54   Prob > chi2 = 0.0000
------------------------------------------------------------------------------

       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+----------------------------------------------------------------
           . |    337           .    -5840.42     11     11702.84    11744.86
-----------------------------------------------------------------------------

.         lincom 1*c.BPgripp9 - 1*c.WPgripp    // Level-2&3 Contextual Effect
------------------------------------------------------------------------------
        info |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
         (1) |   .6772089   .1925793     3.52   0.000     .2997605    1.054657
------------------------------------------------------------------------------
```

One could then test interactions, keeping in mind the need to differentiate effects across all three levels as needed…

Sample Results Section (note this combines across models somewhat)

The extent of individual change in crystallized intelligence (as measured by the information test) and the relationship between intelligence, age, and grip strength was examined in a sample of 337 same-sex twins measured every two years for up to five occasions. Multilevel models were estimated using restricted maximum likelihood. The significance of fixed effects was evaluated with individual Wald tests (i.e., of estimate / SE), whereas random effects were evaluated via likelihood ratio tests (i.e., $-2\Delta LL$ with degrees of freedom equal to the number of new random effects variances and covariances).

A two-level empty means, random intercept model of time nested within person was initially specified and indicated that 83% of the information test outcome variance was between persons. The addition of a random intercept for twin pair resulted in a significant improvement in model fit, $-2\Delta LL(1) = 101.5$, $p < .001$, and revealed that 64% of that between-person variance was due to twin pair (i.e., shared variance between twins from the same pair). Thus, a three-level model was necessary, given that 17% of the variance was at level 1 (within persons over time), 30% was at level 2 (within pairs), and 53% was at level 3 (between pairs). A three-level empty means, random intercept model to decompose the variance in time-varying age revealed that 47% was between pairs (given that the twins initially varied in age from 80 to 100), whereas the remaining 53% was within persons over time—there was no level-2 age variance. Thus, the level-3 cross-sectional and level-1 longitudinal effects of age were modeled separately using baseline age (centered at 85) and time in study, respectively. Preliminary analyses revealed that a linear effect of age at baseline

and a quadratic effect of time in study resulted in the best-fitting model to describe mean change. Although a random linear time slope for twin significantly improved model fit, $-2\Delta LL(2) = 132.0$, $p < .001$, the subsequent addition of a random linear time slope for twin pair did not significantly improve model fit, $-2\Delta LL(2) = 0.8$, $p = .67$, indicating that the 5% of the random linear time slope variance that was due to twin pair was not distinguishable from 0. As a result, the random linear time slope was retained at the twin level only (i.e., level 2 but not level 3).

The prediction of the information test outcome from time-varying grip strength was then examined. A three-level empty means, random intercept model to decompose the variance in grip strength revealed that 36% was between pairs, 29% was within pairs, and 35% was within persons over time. Predictors for grip strength were included via person-mean-centering, in which the within-person effect was represented by the deviation of each occasion's grip strength around each person's mean, the within-pair effect was represented by the deviation of each twin's mean grip strength around each pair's mean, and the between-pair effect was represented by the family mean grip strength (centered at 9 pounds). There was a significant main effect of grip strength at each level. Within persons, for every additional pound of grip strength more than one's own mean, information test at that occasion was expected to be higher by 0.50. Within pairs, for every additional pound of person mean grip strength more than one's family mean, information test for that twin was expected to be higher by 0.91. Between pairs, for every additional pound of family mean grip strength more than other families, information test for the twin pair was expected to be higher by 1.51.

Contextual effects for the differences in effect size across levels were requested using separate statements (i.e., as would be provided directly using grand-mean-centering but including the person and pair means). The pair-level contextual effect was not significant, indicating that the within-pair and between-pair effects were equivalent. Consequently, the model was re-specified to include within-person grip strength, as described previously, along with between-person grip strength to represent the combination of the twin and pair levels, calculated as each person's mean grip strength centered at 9. The between-person effect of grip strength was significant, such that for every additional pound of mean grip strength more than other people, information test for that twin was expected to be higher by 1.18. This effect was significantly larger than the within-person effect of grip strength of 0.51 (i.e., a significant person contextual effect), and thus both the within-person and between-person effects of grip strength were retained.