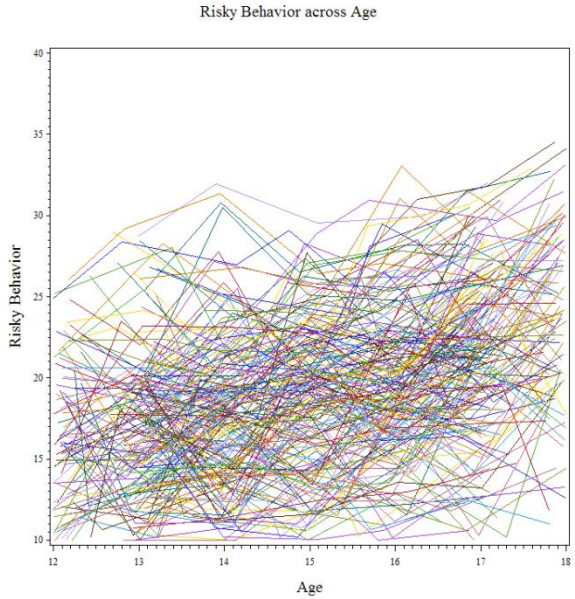
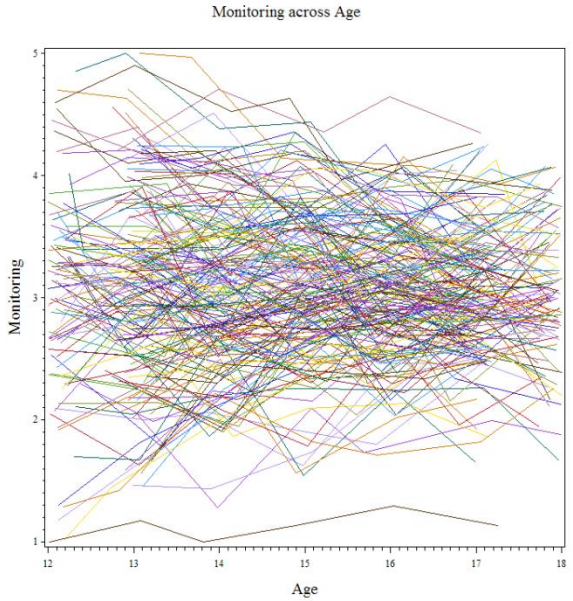
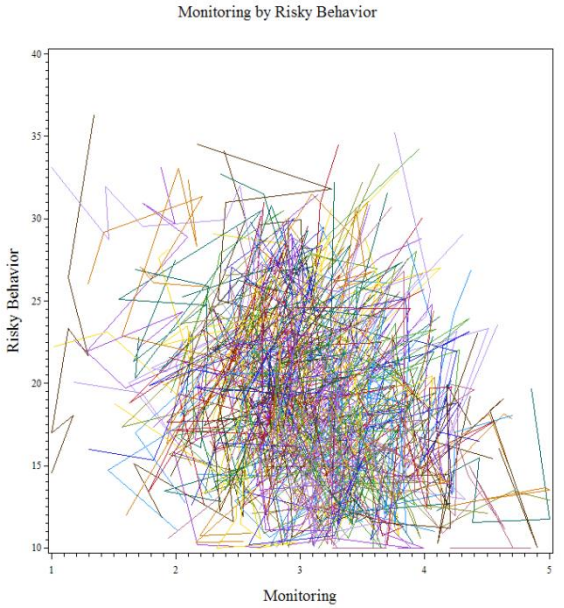
Example 3: Three Ways of Estimating Multivariate Change in Multivariate MLM ("Multilevel SEM") and Single-Level SEM in Mplus v. 8.1+ (complete syntax and output available electronically)

These simulated data are from Hoffman (2015) chapter 9 and include 200 girls measured approximately annually from ages 12–18 (time 0 = age 18) on their risky behavior (the outcome, a sum ranging from 10 to 50) and the extent to which their mothers monitored their activities (the time-varying predictor, a mean ranging from 1 to 5, centered at 3). A time-invariant predictor of the conservativeness of mothers' attitudes about the smoking and drinking (a mean ranging from 1 to 5, centered at 4) was also collected at the age 12 occasion. Here are the individual growth trajectories for risky behavior and monitoring:







Multivariate Multilevel Model 1

Level 1 :

$$y_{tid} = dvR\left[\beta_{0iR} + \beta_{1iR}\left(Age_{tiR} - 18\right) + \beta_{2iR}\left(Age_{tiR} - 18\right)^2 + e_{tiR}\right] + dvM\left[\beta_{0iM} + \beta_{1iM}\left(Age_{tiM} - 18\right) + e_{tiM}\right]$$

Level 2 :

Risky Intercept: $\beta_{0iR} = \gamma_{00R} + \gamma_{01R}\left(Attitudes12_i - 4\right) + U_{0iR}$

Risky Age: $\beta_{1iR} = \gamma_{10R} + \gamma_{11R}\left(Attitudes12_i - 4\right) + U_{1iR}$

Risky Age^2: $\beta_{2iR} = \gamma_{20R}$

Monitor Intercept: $\beta_{0iM} = \gamma_{00M} + \gamma_{01M}\left(Attitudes12_i - 4\right) + U_{0iM}$

Monitor Age: $\beta_{1iM} = \gamma_{10M} + \gamma_{11M}\left(Attitudes12_i - 4\right) + U_{1iM}$

The best-fitting unconditional longitudinal models included fixed quadratic and random linear effects of age for risky behavior, but a random linear effect of age for monitoring (although the fixed linear age slope was nonsignificant). In addition, mother's attitudes significantly predicted the intercept and linear age slope for risky behavior. Although they did not significantly predict monitoring, I have added them here to illustrate how to compute indirect effects.

Chapter 9 began with person-mean-centering and baseline-centering of monitoring as a time-varying predictor of risky behavior. Both were shown to be inadequate because they do not properly distinguish the intercept, linear age slope, and residual variance contained in the monitoring predictor, each of which could potentially relate to those of risky behavior. So the purpose of this example is to demonstrate alternative software methods of estimating models of multivariate change so that you can decide what approach (software and syntax combination) will be most optimal for your own data. See chapter 9 for the results from a directed path model very similar to 2c.

In Mplus, the same Model 1 as an undirected multivariate MLM:

```
TITLE:   Model 1: Undirected Multivariate Growth Model as MLM
DATA:    FILE = Example3.csv;   ! Syntax in same folder as data
VARIABLE:
! List of variables in data file
  NAMES = PersonID Att12 occasion age risky mon roundage
          time att4 timesq mon3;
! Variables to be analyzed in this model
  USEVARIABLE = time timesq att4 risky mon3;
  MISSING ARE ALL (-999);   ! Missing data identifier
! MLM options
  CLUSTER = PersonID;       ! Level-2 ID
  BETWEEN = att4;           ! Observed ONLY level-2 predictors
  WITHIN  = time timesq;    ! Observed ONLY level-1 predictors

ANALYSIS:    TYPE = TWOLEVEL RANDOM; ESTIMATOR = ML;

MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 risky mon3 (Rresvar Mresvar);  ! L1 R: Residual variances (labels)
 Rlin  | risky ON time;         ! Placeholder for R linear age slope
 Rquad | risky ON timesq;       ! Placeholder for R quadratic age slope
 Mlin  | mon3  ON time;         ! Placeholder for M linear age slope
 risky WITH mon3 (ResCov);      ! L1 R: Residual covariance

%BETWEEN%
[risky mon3 Rlin Rquad Mlin];   ! Fixed intercepts, slopes
 risky mon3 (Rintvar Mintvar);  ! L2 G: Random intercept variances (labels)
 Rlin Mlin  (Rlinvar Mlinvar);  ! L2 G: Random linear age slope variances
 Rquad@0;                       ! No quadratic age slope variance

 risky Rlin ON att4;            ! Att-> R int, linear age slope
  mon3 Mlin ON att4;            ! Att-> M int, linear age slope
 risky WITH Rlin  (RIntLin);    ! R Int-slope covariance (label)
 mon3  WITH Mlin  (MIntLin);    ! M Int-slope covariance (label)

 risky WITH mon3  (IntCov);     ! L2 G: Random intercept covariance
 Rlin  WITH Mlin  (LinCov);     ! L2 G: Random linear age slope covariance
 mon3  WITH Rlin  (Int2Lin);    ! L2 G: M int, R slope covariance
 Mlin  WITH risky (Lin2Int);    ! L2 G: M slope, R int covariance

MODEL CONSTRAINT:  ! Linear combinations of any parameter
! First need to name each new combination
NEW(ResCor IntCor LinCor RIScor MIScor I2SCor S2ICor);

! Estimating correlations found in SAS RCORR and GCORR
! Corr = Cov / (SQRT(Yvar)*SQRT(Xvar))
  ResCor = ResCov  / (SQRT(Rresvar)*SQRT(Mresvar));
  IntCor = IntCov  / (SQRT(Rintvar)*SQRT(Mintvar));
  LinCor = LinCov  / (SQRT(Rlinvar)*SQRT(Mlinvar));
  RIScor = RIntLin / (SQRT(Rintvar)*SQRT(Rlinvar));
  MIScor = MIntLin / (SQRT(Mintvar)*SQRT(Mlinvar));
  I2Scor = Int2Lin / (SQRT(Mintvar)*SQRT(Rlinvar));
  S2Icor = Lin2Int / (SQRT(Mlinvar)*SQRT(Rintvar));
```

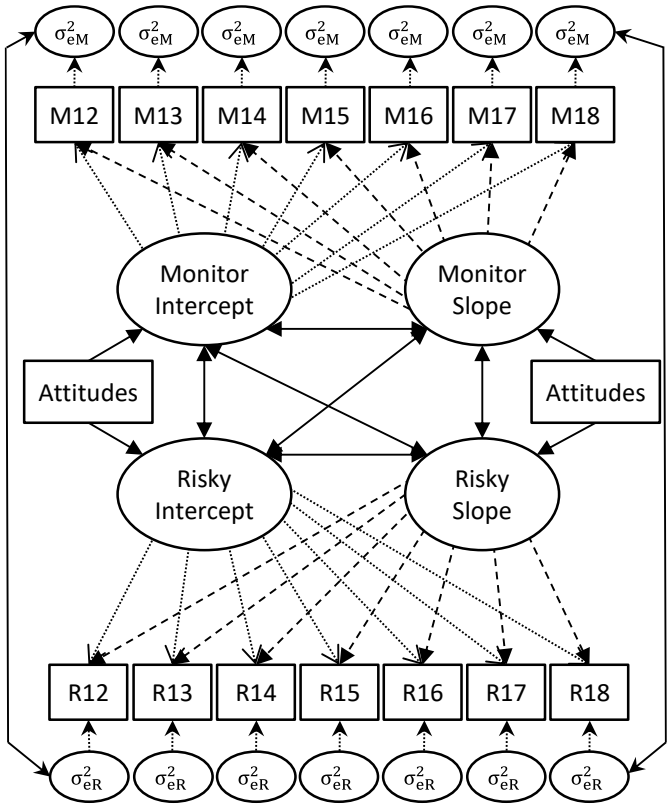
```
Number of Free Parameters                       22
Loglikelihood
          H0 Value                       -4391.884
Information Criteria
          Akaike (AIC)                    8827.768
          Bayesian (BIC)                  8943.141
          Sample-Size Adjusted BIC        8873.255
            (n* = (n + 2) / 24)
```

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level				
RISKY WITH				
MON3	0.287	0.028	10.441	0.000
Residual Variances				
RISKY	8.352	0.374	22.351	0.000
MON3	0.081	0.004	22.354	0.000
Between Level				
RLIN ON				
ATT4	-0.518	0.104	-4.963	0.000
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RISKY ON				
ATT4	-3.160	0.551	-5.737	0.000
MON3 ON				
ATT4	-0.044	0.057	-0.779	0.436
RISKY WITH				
RLIN	1.878	0.356	5.273	0.000
MLIN	0.040	0.039	1.044	0.296
MON3 WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.106	0.031	-3.449	0.001
RLIN WITH				
MLIN	-0.018	0.007	-2.478	0.013
RISKY WITH				
MON3	-0.853	0.168	-5.076	0.000
Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
RISKY	23.322	0.348	67.075	0.000
MON3	0.063	0.034	1.839	0.066
RLIN	1.975	0.138	14.259	0.000
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
RISKY	18.049	2.202	8.198	0.000
MON3	0.195	0.023	8.371	0.000
RLIN	0.484	0.080	6.071	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESCOR	**0.350**	**0.028**	**12.607**	**0.000**
INTCOR	**-0.455**	**0.074**	**-6.119**	**0.000**
LINCOR	**-0.255**	**0.103**	**-2.483**	**0.013**
RISCOR	0.635	0.057	11.088	0.000
MISCOR	-0.009	0.089	-0.105	0.917
I2SCOR	-0.346	0.095	-3.646	0.000
S2ICOR	0.093	0.087	1.066	0.286

In Mplus, the same Model 1 as an undirected single-level SEM:

```
TITLE:   Model 1: Undirected Multivariate Growth Model as Single-Level SEM
DATA:    FILE = Example3.csv;    ! Syntax in same folder as data
! Unstacking to multivariate format
DATA LONGTOWIDE:
! Names of old stacked former variables (without numbers)
  LONG = risky|mon3|time;
! Names of new multivariate variables (that use numbers)
  WIDE = risky12-risky18|mon12-mon18|age12-age18;
! Variable with level-2 ID info
  IDVARIABLE = PersonID;
! Old level-1 identifier
  REPETITION = roundage (12 13 14 15 16 17 18);
VARIABLE:
! List of variables in original data file
  NAMES = PersonID Att12 occasion age risky mon roundage
          time att4 timesq mon3;
! Variables to be analyzed in this model
  USEVARIABLE = att4 age12-age18 mon12-mon18 risky12-risky18;
  MISSING ARE ALL (-999);    ! Missing data identifier
  TSCORES = age12-age18;     ! Exact time indicator
ANALYSIS:    TYPE = RANDOM; ESTIMATOR = ML; MODEL = NOCOVARIANCES;
MODEL:   ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0
 risky12-risky18 (Rresvar);        ! L1 R: R residual variances held equal
 mon12-mon18     (Mresvar);        ! L1 R: M residual variances held equal

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rlin Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mlin | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rlin Rquad Mint Mlin];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rlin Mint Mlin (Rintvar Rlinvar Mintvar Mlinvar); Rquad@0;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rlin (Rintlin); Mint WITH Mlin (Mintlin);
! Attitudes --> R int, R linear slope, M int, M linear slope
  Rint Rlin Mint Mlin ON att4;
! Covariances between outcomes
  Rint WITH Mint (IntCov);      ! L2 G: Random intercept covariance
  Rlin WITH Mlin (LinCov);      ! L2 G: Random linear age slope covariance
  Mint WITH Rlin (Int2Lin);     ! L2 G: M int, R slope covariance
  Mlin WITH Rint (Lin2Int);     ! L2 G: M slope, R int covariance
! Residual WP covariance between same ages, held equal across age
  risky12-risky18 PWITH mon12-mon18 (ResCov);

MODEL CONSTRAINT:           ! Linear combinations of any parameter
NEW(ResCor IntCor LinCor);  ! First need to name each new created effect
! Estimating correlations found in SAS RCORR and GCORR
! Corr = Cov / (SQRT(Yvar)*SQRT(Xvar))
  ResCor = ResCov  / (SQRT(Rresvar)*SQRT(Mresvar));
  IntCor = IntCov  / (SQRT(Rintvar)*SQRT(Mintvar));
  LinCor = LinCov  / (SQRT(Rlinvar)*SQRT(Mlinvar));
```

Quadratic fixed effect for risky outcome not shown in diagram…



For balanced time, a linear growth model would look like this instead (add Mquad as third variable before |):

```
Mint Mlin | mon12@-6 mon13@-5 mon14@-4 mon15@-3
            mon16@-2 mon17@-1 mon18@0;
```

MODEL FIT INFORMATION

Number of Free Parameters	22
Loglikelihood	
H0 Value	-4391.884
Information Criteria	
Akaike (AIC)	8827.768
Bayesian (BIC)	8900.331
Sample-Size Adjusted BIC (n* = (n + 2) / 24)	8830.633

MODEL RESULTS

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
RINT ON				
ATT4	-3.160	0.551	-5.737	0.000
RLIN ON				
ATT4	-0.518	0.104	-4.963	0.000
MINT ON				
ATT4	-0.044	0.057	-0.779	0.436
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RINT WITH				
RLIN	1.878	0.356	5.273	0.000
MINT	-0.853	0.168	-5.076	0.000
MLIN	0.040	0.039	1.044	0.296
MINT WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.106	0.031	-3.449	0.001
RLIN WITH				
MLIN	-0.018	0.007	-2.478	0.013
RISKY12 WITH				
MON12	0.287	0.028	10.441	0.000
RISKY13 WITH				
MON13	0.287	0.028	10.441	0.000
RISKY14 WITH				
MON14	0.287	0.028	10.441	0.000
RISKY15 WITH				
MON15	0.287	0.028	10.441	0.000
RISKY16 WITH				
MON16	0.287	0.028	10.441	0.000
RISKY17 WITH				
MON17	0.287	0.028	10.441	0.000
RISKY18 WITH				
MON18	0.287	0.028	10.441	0.000
Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
MON12	0.000	0.000	999.000	999.000
MON13	0.000	0.000	999.000	999.000
MON14	0.000	0.000	999.000	999.000
MON15	0.000	0.000	999.000	999.000
MON16	0.000	0.000	999.000	999.000
MON17	0.000	0.000	999.000	999.000
MON18	0.000	0.000	999.000	999.000
RISKY12	0.000	0.000	999.000	999.000
RISKY13	0.000	0.000	999.000	999.000
RISKY14	0.000	0.000	999.000	999.000
RISKY15	0.000	0.000	999.000	999.000
RISKY16	0.000	0.000	999.000	999.000
RISKY17	0.000	0.000	999.000	999.000
RISKY18	0.000	0.000	999.000	999.000
RINT	23.322	0.348	67.074	0.000
RLIN	1.975	0.138	14.259	0.000
MINT	0.063	0.034	1.839	0.066
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
MON12	0.081	0.004	22.354	0.000
MON13	0.081	0.004	22.354	0.000
MON14	0.081	0.004	22.354	0.000
MON15	0.081	0.004	22.354	0.000
MON16	0.081	0.004	22.354	0.000
MON17	0.081	0.004	22.354	0.000
MON18	0.081	0.004	22.354	0.000
RISKY12	8.352	0.374	22.351	0.000
RISKY13	8.352	0.374	22.351	0.000
RISKY14	8.352	0.374	22.351	0.000
RISKY15	8.352	0.374	22.351	0.000
RISKY16	8.352	0.374	22.351	0.000
RISKY17	8.352	0.374	22.351	0.000
RISKY18	8.352	0.374	22.351	0.000
RINT	18.049	2.202	8.198	0.000
RLIN	0.484	0.080	6.071	0.000
MINT	0.195	0.023	8.371	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESCOR	**0.350**	**0.028**	**12.607**	**0.000**
INTCOR	**-0.455**	**0.074**	**-6.119**	**0.000**
LINCOR	**-0.255**	**0.103**	**-2.483**	**0.013**

Model 2a: Partially Directed Path Multivariate MLM in Mplus: Monitor → Risky for BP intercepts and slopes, but WP residuals covary

```
TITLE:  Model 2a: Partially Directed Multivariate Growth Model as MLM
        L1 WP effect as residual covariance

( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 MLM )

MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 risky mon3 (Rresvar Mresvar); ! L1 R: Residual variances (labels)
 Rlin  | risky ON time;        ! Placeholder for R linear age slope
 Rquad | risky ON timesq;      ! Placeholder for R quadratic age slope
 Mlin  | mon3  ON time;        ! Placeholder for M linear age slope
 risky WITH mon3 (ResCov);     ! L1 R: Still residual covariance

%BETWEEN%
[risky mon3 Rlin Rquad Mlin];  ! Fixed intercepts, slopes
 risky mon3 (Rintvar Mintvar); ! L2 G: Random intercept variances (labels)
 Rlin Mlin  (Rlinvar Mlinvar); ! L2 G: Random linear age slope variances
 Rquad@0;                      ! No quadratic age slope variance
 risky Rlin ON att4;           ! Att-> R int, linear age slope
  mon3 Mlin ON att4;           ! Att-> M int, linear age slope
 risky WITH Rlin (RIntLin);    ! R Int-slope covariance (label)
 mon3  WITH Mlin (MIntLin);    ! M Int-slope covariance (label)

! Although we have changed the int-int and slope-slope relations to direct
! paths from M -> R instead of covariances, they still represent total L2
! BP relationships because the L1 relationship is still a covariance

 risky ON   mon3 (BPIntEff);    ! Total L2 BP intercept effect
 Rlin  ON   Mlin (BPLinEff);    ! Total L2 BP age slope effect

 mon3  WITH Rlin  (Int2Lin);    ! L2 G: M int, R slope covariance
 Mlin  WITH risky (Lin2Int);    ! L2 G: M slope, R int covariance

MODEL CONSTRAINT:
! All values below are variances from undirected model 1
NEW(ResCor IntStd LinStd);

! Corr = Cov / (SQRT(Yvar)*SQRT(Xvar))
  ResCor = ResCov / (SQRT(8.3538)*SQRT(0.08077));     ! WP Res corr

! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644);  ! STD BP Int effect
  LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830);  ! STD BP Slope effect
```

This is an equivalent model, just with a different way of specifying the level-2 BP intercept-to-intercept and slope-to-slope relationships.

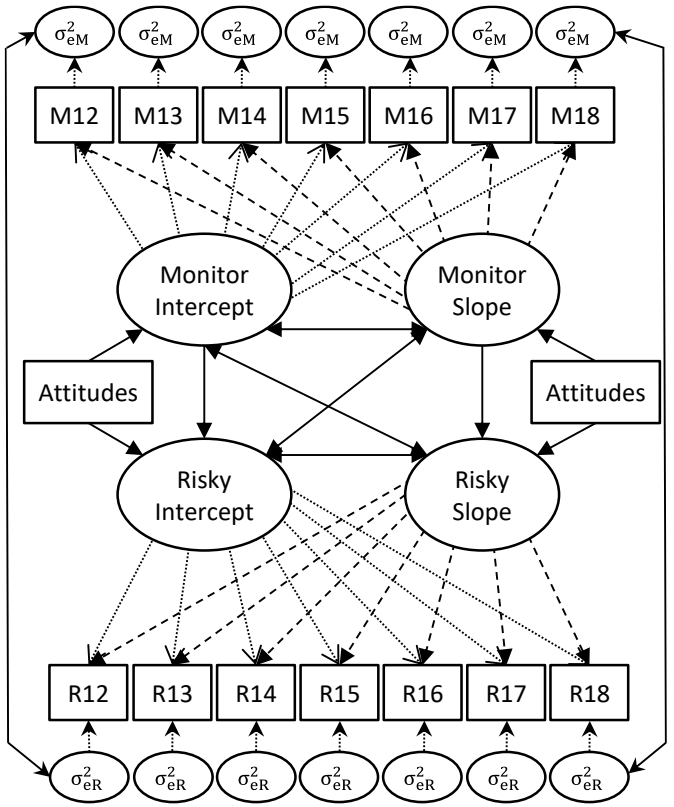
	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level				
RISKY WITH				
MON3	0.287	0.028	10.441	0.000
Residual Variances				
RISKY	8.352	0.374	22.351	0.000
MON3	0.081	0.004	22.354	0.000
Between Level – **new parameters are in BOLD underline**				
RLIN ON				
MLIN	**-1.736**	**0.713**	**-2.434**	**0.015**
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RISKY ON				
ATT4	-3.354	0.528	-6.348	0.000
MON3	**-4.380**	**0.797**	**-5.497**	**0.000**
MON3 ON				
ATT4	-0.044	0.057	-0.779	0.436
RISKY WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MON3 WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001
Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
RISKY	23.598	0.338	69.837	0.000
MON3	0.063	0.034	1.839	0.066
RLIN	1.969	0.139	14.195	0.000
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
RISKY	14.315	2.030	7.053	0.000
MON3	0.195	0.023	8.371	0.000
RLIN	0.453	0.081	5.564	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESCOR	0.350	0.034	10.441	0.000
INTSTD	-0.455	0.083	-5.497	0.000
LINSTD	-0.254	0.104	-2.434	0.015

In Mplus, Model 2a as a partially directed single-level SEM: Monitor → Risky for intercepts and slopes, but residuals covary

```
TITLE:  Model 2a: Partially Directed Multivariate Growth Model as
        Single-Level SEM, L1 WP effect as residual covariance

( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 SEM )

MODEL:  ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0
 risky12-risky18 (Rresvar);        ! L1 R: R residual variances held equal
 mon12-mon18     (Mresvar);        ! L1 R: M residual variances held equal

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rlin Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mlin | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rlin Rquad Mint Mlin];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rlin Mint Mlin (Rintvar Rlinvar Mintvar Mlinvar); Rquad@0;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rlin (Rintlin); Mint WITH Mlin (Mintlin);
! Attitudes --> R int, R linear slope, M int, M linear slope
  Rint Rlin Mint Mlin ON att4;

! Although we have changed the int-int and slope-slope relations to direct
! paths from M -> R instead of covariances, they still represent total L2
! BP relationships because the L1 relationship is still a covariance

  Rint ON Mint   (BPIntEff);    ! Total L2 BP intercept effect
  Rlin ON Mlin   (BPLinEff);    ! Total L2 BP age slope effect

  Mint WITH Rlin (Int2Lin);     ! L2 G: M int, R slope covariance
  Mlin WITH Rint (Lin2Int);     ! L2 G: M slope, R int covariance

! Residual WP covariance between same ages, held equal across age
  risky12-risky18 PWITH mon12-mon18 (ResCov);

MODEL CONSTRAINT:  ! All values below are variances from undirected model 1
  NEW(ResCor IntStd LinStd);

! Corr = Cov / (SQRT(Yvar)*SQRT(Xvar))
  ResCor = ResCov / (SQRT(8.3538)*SQRT(0.08077));    ! WP Res corr

! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644); ! STD BP Int effect
  LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830); ! STD BP Slope effect
```

This is an equivalent model, just with a different way of specifying the level-2 BP intercept-to-intercept and slope-to-slope relationships.

Quadratic fixed effect for risky outcome not shown in diagram…



For balanced time, a linear growth model would look like this instead (add Mquad as third variable before |):

```
Mint Mlin | mon12@-6 mon13@-5 mon14@-4 mon15@-3
            mon16@-2 mon17@-1 mon18@0;
```

MODEL RESULTS – **changed parameters are in BOLD underline**

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
RINT ON				
MINT	**-4.380**	**0.797**	**-5.496**	**0.000**
RLIN ON				
MLIN	**-1.735**	**0.713**	**-2.434**	**0.015**
RINT ON				
ATT4	-3.354	0.528	-6.348	0.000
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MINT ON				
ATT4	-0.044	0.057	-0.779	0.436
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RINT WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MINT WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001
RISKY12 WITH				
MON12	0.287	0.028	10.441	0.000
RISKY13 WITH				
MON13	0.287	0.028	10.441	0.000
RISKY14 WITH				
MON14	0.287	0.028	10.441	0.000
RISKY15 WITH				
MON15	0.287	0.028	10.441	0.000
RISKY16 WITH				
MON16	0.287	0.028	10.441	0.000
RISKY17 WITH				
MON17	0.287	0.028	10.441	0.000
RISKY18 WITH				
MON18	0.287	0.028	10.441	0.000

Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
RISKY12	0.000	0.000	999.000	999.000
RISKY13	0.000	0.000	999.000	999.000
RISKY14	0.000	0.000	999.000	999.000
RISKY15	0.000	0.000	999.000	999.000
RISKY16	0.000	0.000	999.000	999.000
RISKY17	0.000	0.000	999.000	999.000
RISKY18	0.000	0.000	999.000	999.000
MON12	0.000	0.000	999.000	999.000
MON13	0.000	0.000	999.000	999.000
MON14	0.000	0.000	999.000	999.000
MON15	0.000	0.000	999.000	999.000
MON16	0.000	0.000	999.000	999.000
MON17	0.000	0.000	999.000	999.000
MON18	0.000	0.000	999.000	999.000
RINT	23.598	0.338	69.836	0.000
RLIN	1.969	0.139	14.195	0.000
MINT	0.063	0.034	1.839	0.066
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
RISKY12	8.352	0.374	22.351	0.000
RISKY13	8.352	0.374	22.351	0.000
RISKY14	8.352	0.374	22.351	0.000
RISKY15	8.352	0.374	22.351	0.000
RISKY16	8.352	0.374	22.351	0.000
RISKY17	8.352	0.374	22.351	0.000
RISKY18	8.352	0.374	22.351	0.000
MON12	0.081	0.004	22.354	0.000
MON13	0.081	0.004	22.354	0.000
MON14	0.081	0.004	22.354	0.000
MON15	0.081	0.004	22.354	0.000
MON16	0.081	0.004	22.354	0.000
MON17	0.081	0.004	22.354	0.000
MON18	0.081	0.004	22.354	0.000
RINT	14.315	2.030	7.053	0.000
RLIN	0.453	0.081	5.564	0.000
MINT	0.195	0.023	8.371	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESCOR	0.350	0.034	10.441	0.000
INTSTD	-0.455	0.083	-5.496	0.000
LINSTD	-0.254	0.104	-2.434	0.015

Model 2b: Partially Directed Path Multivariate MLM in Mplus: Monitor → Risky for WP residuals within L1 model
Also demonstrating how to request BP indirect effects

```
TITLE:  Model 2b: Partially Directed Multivariate Growth Model as MLM
        L1 WP effect as direct path specified in L1 WITHIN

( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 MLM )

MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 risky mon3 (Rresvar Mresvar); ! L1 R: Residual variances (labels)
 Rlin  | risky ON time;        ! Placeholder for R linear age slope
 Rquad | risky ON timesq;      ! Placeholder for R quadratic age slope
 Mlin  | mon3  ON time;        ! Placeholder for M linear age slope
 risky ON mon3 (ResEff);       ! L1 WP fixed effect M->R here (label)

%BETWEEN%
[risky mon3 Rlin Rquad Mlin];  ! Fixed intercepts, slopes
 risky mon3 (Rintvar Mintvar); ! L2 G: Random intercept variances (labels)
 Rlin Mlin  (Rlinvar Mlinvar); ! L2 G: Random linear age slope variances
 Rquad@0;                      ! No quadratic age slope variance
 risky Rlin ON att4 (XtoYint XtoYlin);  ! Att-> R int, linear age slope
  mon3 Mlin ON att4 (XtoMint XtoMlin);  ! Att-> M int, linear age slope
 risky WITH Rlin (RIntLin);     ! R Int-slope covariance (label)
  mon3 WITH Mlin (MIntLin);     ! M Int-slope covariance (label)

! Although the intercept -> intercept path remains the total L2 BP effect,
! now the slope -> slope path becomes the L2 contextual effect instead

 risky ON   mon3  (BPIntEff);   ! STILL total L2 BP intercept effect
 Rlin  ON   Mlin  (LinCont);    ! NOW L2 contextual linear slope effect

 mon3  WITH Rlin  (Int2Lin);    ! L2 G: M int, R slope covariance
 Mlin  WITH risky (Lin2Int);    ! L2 G: M slope, R int covariance

MODEL CONSTRAINT:
NEW(ResStd IntStd BPLinEff LinStd indBPint indBPlin);

! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  ResStd = ResEff   * SQRT(0.08077) / SQRT(8.3538);  ! STD WP Res effect
  IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644); ! STD BP Int effect
  BPLinEff = ResEff + LinCont;                       ! WP + Context = BP lin
  LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830); ! STD BP Slope effect
  indBPint = XtoMint * BPIntEff;              ! BP intercept indirect effect
  indBPlin = XtoMlin * BPLinEff;              ! BP age slope indirect effect
```

This is still an equivalent model, just with a different way of specifying the level-1 WP residual-to-residual relationship. This syntax method will only work for level-1 effects that are fixed, though…

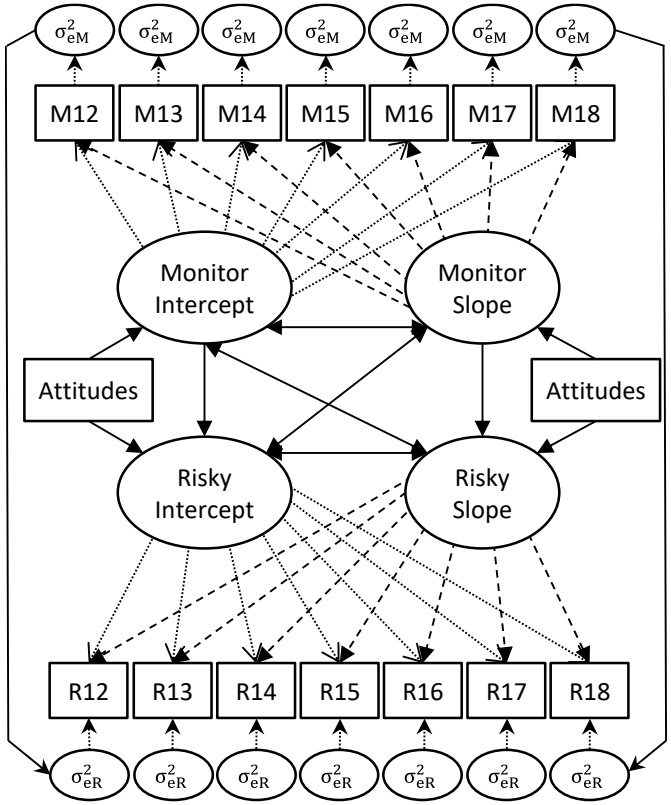
	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level – **new parameters are in BOLD underline**				
RISKY ON				
MON3	**3.559**	**0.301**	**11.809**	**0.000**
Residual Variances				
RISKY	7.329	0.328	22.353	0.000
MON3	0.081	0.004	22.354	0.000
Between Level – **changed parameters are in BOLD underline**				
RLIN ON				
MLIN	**-5.294**	**0.806**	**-6.569**	**0.000**
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RISKY ON				
ATT4	-3.354	0.528	-6.348	0.000
MON3	-4.380	0.797	-5.497	0.000
MON3 ON				
ATT4	-0.044	0.057	-0.779	0.436
RISKY WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MON3 WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001
Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
RISKY	23.598	0.338	69.837	0.000
MON3	0.063	0.034	1.839	0.066
RLIN	1.969	0.139	14.195	0.000
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
RISKY	14.315	2.030	7.053	0.000
MON3	0.195	0.023	8.371	0.000
RLIN	0.453	0.081	5.564	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESSTD	0.350	0.034	10.441	0.000
INTSTD	-0.455	0.083	-5.497	0.000
BPLINEFF	**-1.736**	**0.713**	**-2.434**	**0.015**
LINSTD	-0.254	0.104	-2.434	0.015
INDBPINT	0.194	0.251	0.772	0.440
INDBPLIN	-0.006	0.024	-0.239	0.811

In Mplus, Model 2b as a partially directed single-level SEM: Monitor → Risky for WP residuals using structured residuals

```
TITLE:   Model 2b: Partially Directed Multivariate Growth Model as Single-
         Level SEM, L1 WP effect as direct path using structured residuals
( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 SEM )
MODEL:   ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rlin Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mlin | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rlin Rquad Mint Mlin];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rlin Mint Mlin (Rintvar Rlinvar Mintvar Mlinvar); Rquad@0;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rlin (Rintlin); Mint WITH Mlin (Mintlin);
! Attitudes --> R int, R linear slope, M int, M linear slope
  Rint Rlin Mint Mlin ON att4 (XtoYint XtoYlin XtoMint XtoMlin);
  Rint ON Mint   (BPIntEff);     ! Total BP intercept effect
  Rlin ON Mlin   (BPLinEff);     ! Total BP age slope effect
  Mint WITH Rlin (Int2Lin);      ! L2 G: M int, R slope covariance
  Mlin WITH Rint (Lin2Int);      ! L2 G: M slope, R int covariance

! Define new latent factors for residuals at each occasion
  Frisky12 BY risky12@1; Frisky13 BY risky13@1; Frisky14 BY risky14@1;
  Frisky15 BY risky15@1; Frisky16 BY risky16@1; Frisky17 BY risky17@1;
  Frisky18 BY risky18@1; Fmon12 BY mon12@1; Fmon13 BY mon13@1;
  Fmon14 BY mon14@1; Fmon15 BY mon15@1; Fmon16 BY mon16@1;
  Fmon17 BY mon17@1; Fmon18 BY mon18@1;
! All factor means fixed to 0
  [Frisky12-Frisky18@0 Fmon12-Fmon18@0];
! Shut off old residual variances
  risky12-risky18@0 mon12-mon18@0;
! Hold new residual variances equal over time
  Frisky12-Frisky18 (Rresvar); ! L1 R: R residual variances held equal
  Fmon12-Fmon18     (Mresvar); ! L1 R: M residual variances held equal
! Factor residual WP effect between same ages, held equal across age
  Frisky12-Frisky18 PON Fmon12-Fmon18 (ResEff);

MODEL CONSTRAINT:
NEW(ResStd IntStd LinStd indBPint indBPlin);
! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  ResStd = ResEff   * SQRT(0.08077) / SQRT(8.3538);  ! STD WP Res effect
  IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644); ! STD BP Int effect
  LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830); ! STD BP Slope effect
  indBPint = XtoMint * BPIntEff;           ! BP intercept indirect effect
  indBPlin = XtoMlin * BPLinEff;           ! BP age slope indirect effect
```

This is still an equivalent model, just with a different way of specifying the level-2 BP intercept-to-intercept and slope-to-slope relationships.

Quadratic fixed effect for risky outcome not shown in diagram…



For balanced time, a linear growth model would look like this instead (add Mquad as third variable before |):

```
Mint Mlin | mon12@-6 mon13@-5 mon14@-4 mon15@-3
            mon16@-2 mon17@-1 mon18@0;
```

MODEL RESULTS – **changed parameters are in BOLD underline**

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Factor loadings set to 1 omitted				
RINT ON				
MINT	-4.380	0.797	-5.496	0.000
RLIN ON				
MLIN	-1.736	0.713	-2.434	0.015
FRISKY12 ON				
FMON12	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY13 ON				
FMON13	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY14 ON				
FMON14	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY15 ON				
FMON15	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY16 ON				
FMON16	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY17 ON				
FMON17	**3.563**	**0.302**	**11.810**	**0.000**
FRISKY18 ON				
FMON18	**3.563**	**0.302**	**11.810**	**0.000**
RINT ON				
ATT4	-3.354	0.528	-6.348	0.000
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MINT ON				
ATT4	-0.044	0.057	-0.779	0.436
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RINT WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MINT WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001

Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
Intercepts fixed to 0 omitted				
RINT	23.598	0.338	69.836	0.000
RLIN	1.969	0.139	14.195	0.000
MINT	0.063	0.034	1.839	0.066
MLIN	-0.003	0.008	-0.380	0.704
Variances				
FMON12	0.081	0.004	22.327	0.000
FMON13	0.081	0.004	22.327	0.000
FMON14	0.081	0.004	22.327	0.000
FMON15	0.081	0.004	22.327	0.000
FMON16	0.081	0.004	22.327	0.000
FMON17	0.081	0.004	22.327	0.000
FMON18	0.081	0.004	22.327	0.000
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
Residual variances fixed to 0 omitted				
FRISKY12	7.328	0.328	22.349	0.000
FRISKY13	7.328	0.328	22.349	0.000
FRISKY14	7.328	0.328	22.349	0.000
FRISKY15	7.328	0.328	22.349	0.000
FRISKY16	7.328	0.328	22.349	0.000
FRISKY17	7.328	0.328	22.349	0.000
FRISKY18	7.328	0.328	22.349	0.000
RINT	14.315	2.030	7.053	0.000
RLIN	0.453	0.081	5.564	0.000
MINT	0.195	0.023	8.371	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESSTD	0.350	0.034	10.441	0.000
INTSTD	-0.455	0.083	-5.496	0.000
LINSTD	-0.254	0.104	-2.434	0.015
INDBPINT	0.194	0.251	0.772	0.440
INDBPLIN	-0.006	0.024	-0.239	0.811

Model 2c: Partially Directed Path Multivariate MLM in Mplus: Monitor → Risky for WP residuals within L2 model via placeholder syntax
Also demonstrating how to request BP indirect effects

```
TITLE:  Model 2c: Partially Directed Multivariate Growth Model as MLM
        L1 WP effect as direct path specified in L2 BETWEEN
( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 MLM )

MODEL:  ! R = risky behavior, M = monitoring
%WITHIN%
 risky mon3 (Rresvar Mresvar); ! L1 R: Residual variances (labels)
 Rlin  | risky ON time;        ! Placeholder for R linear age slope
 Rquad | risky ON timesq;      ! Placeholder for R quadratic age slope
 Mlin  | mon3  ON time;        ! Placeholder for M linear age slope
 WPres | risky ON mon3;        ! NEW placeholder for L1 WP effect M->R

%BETWEEN%
[risky mon3 Rlin Rquad Mlin];  ! Fixed intercepts, slopes
 risky mon3 (Rintvar Mintvar); ! L2 G: Random intercept variances (labels)
 Rlin Mlin  (Rlinvar Mlinvar); ! L2 G: Random linear age slope variances
 Rquad@0;                      ! No quadratic age slope variance
risky Rlin ON att4 (XtoYint XtoYlin);  ! Att-> R int, linear age slope
 mon3 Mlin ON att4 (XtoMint XtoMlin);  ! Att-> M int, linear age slope
 risky WITH Rlin (RIntLin);     ! R Int-slope covariance (label)
  mon3 WITH Mlin (MIntLin);     ! M Int-slope covariance (label)

! And now both the intercept -> intercept path and the slope -> slope path
! are L2 contextual effects given the L1 placeholder for WP residual effect

 risky ON   mon3  (IntCont);    ! NOW L2 contextual intercept effect
 Rlin  ON   Mlin  (LinCont);    ! NOW L2 contextual slope effect
 mon3  WITH Rlin  (Int2Lin);    ! L2 G: M int, R slope covariance
 Mlin  WITH risky (Lin2Int);    ! L2 G: M slope, R int covariance

 [WPres] (ResEff);  ! Fixed effect for L1 WP M->R (as defined earlier)
  WPres@0;          ! No random L1 WP M->R effect variance

MODEL CONSTRAINT:
NEW(ResStd BPIntEff IntStd BPLinEff LinStd indBPint indBPlin);

! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  ResStd = ResEff   * SQRT(0.08077) / SQRT(8.3538);   ! STD WP Res effect
  BPIntEff = ResEff + IntCont;                        ! WP + Context = BP int
  IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644);  ! STD BP Int effect
  BPLinEff = ResEff + LinCont;                        ! WP + Context = BP lin
  LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830);  ! STD BP Slope effect
  indBPint = XtoMint * BPIntEff;              ! BP intercept indirect effect
  indBPlin = XtoMlin * BPLinEff;              ! BP age slope indirect effect
```

This is still an equivalent model, just with a different syntax for specifying the same level-1 WP residual-to-residual directed relationship. This is the version that is necessary in order to have the level-1 effect become random or systematically varying (i.e., add cross-level interactions). **But if you switch to Bayes estimation, then all the L2 effects are BP instead (see Hoffman 2019 AMPPS)!!!**

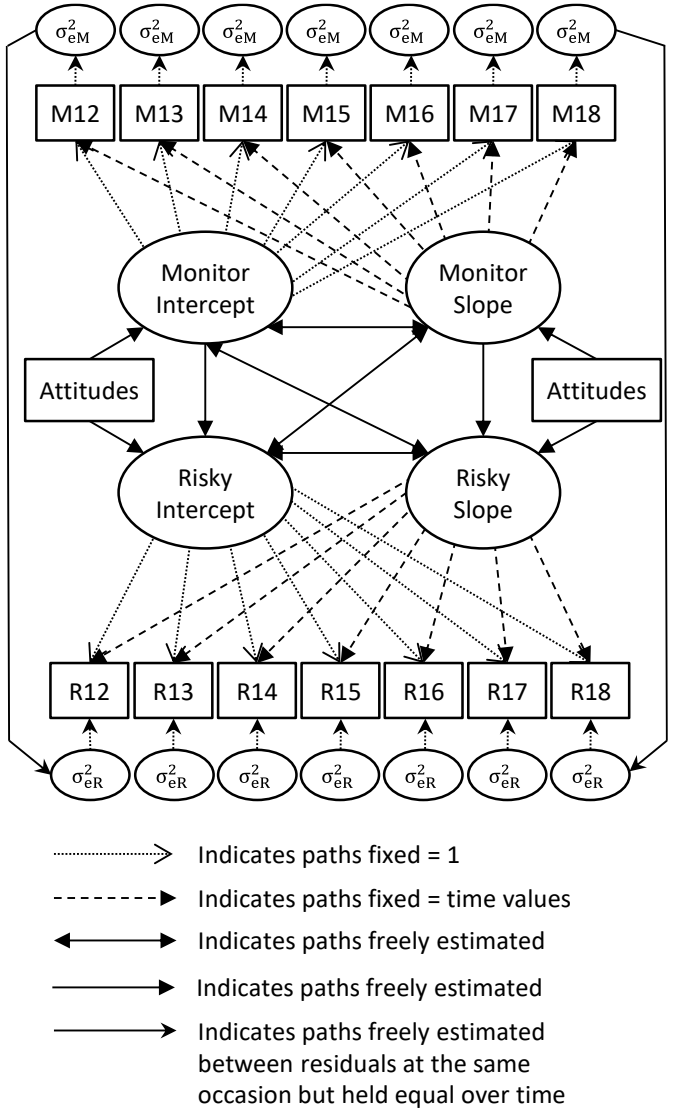
	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Within Level				
Residual Variances				
RISKY	7.329	0.328	22.353	0.000
MON3	0.081	0.004	22.354	0.000
Between Level – **changed parameters are in BOLD underline**				
RLIN ON				
MLIN	-5.294	0.806	-6.569	0.000
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RISKY ON				
ATT4	-3.354	0.528	-6.348	0.000
MON3	**-7.938**	**0.872**	**-9.099**	**0.000**
MON3 ON				
ATT4	-0.044	0.057	-0.779	0.436
RISKY WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MON3 WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001
Means				
RQUAD	0.147	0.021	7.117	0.000
WPRES (here now)	**3.559**	**0.301**	**11.810**	**0.000**
Intercepts				
RISKY	23.598	0.338	69.837	0.000
MON3	0.063	0.034	1.839	0.066
RLIN	1.969	0.139	14.195	0.000
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
WPRES	0.000	0.000	999.000	999.000
Residual Variances				
RISKY	14.315	2.030	7.053	0.000
MON3	0.195	0.023	8.371	0.000
RLIN	0.453	0.081	5.564	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESSTD	0.350	0.030	11.810	0.000
BPINTEFF	**-4.380**	**0.797**	**-5.496**	**0.000**
INTSTD	-0.455	0.083	-5.496	0.000
BPLINEFF	**-1.735**	**0.713**	**-2.434**	**0.015**
LINSTD	-0.254	0.104	-2.434	0.015
INDBPINT	**0.194**	**0.251**	**0.772**	**0.440**
INDBPLIN	**-0.006**	**0.024**	**-0.239**	**0.811**

In Mplus, Model 2c as a partially directed single-level SEM: Monitor → Risky for WP residuals using original residuals

```
TITLE:  Model 2c: Partially Directed Multivariate Growth Model as Single-
Level SEM, L1 WP effect as direct path using original residuals

( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 SEM )
MODEL:  ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0
 risky12-risky18 (Rresvar);        ! L1 R: R residual variances held equal
 mon12-mon18     (Mresvar);        ! L1 R: M residual variances held equal

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rlin Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mlin | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rlin Rquad Mint Mlin];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rlin Mint Mlin (Rintvar Rlinvar Mintvar Mlinvar); Rquad@0;
! L2 G: Within-variable random int-slope covariances for R, M
  Rint WITH Rlin (Rintlin); Mint WITH Mlin (Mintlin);
! Attitudes --> R int, R linear slope, M int, M linear slope
  Rint Rlin Mint Mlin ON att4 (XtoYint XtoYlin XtoMint XtoMlin);

  Rint ON Mint   (IntCont);     ! NOW L2 contextual intercept effect
  Rlin ON Mlin   (LinCont);     ! NOW L2 contextual age slope effect
  Mint WITH Rlin (Int2Lin);     ! L2 G: M int, R slope covariance
  Mlin WITH Rint (Lin2Int);     ! L2 G: M slope, R int covariance

! Residual WP slope between same ages, held equal across age
  risky12-risky18 PON mon12-mon18 (ResEff);

MODEL CONSTRAINT:
NEW(ResStd BPIntEff IntStd BPLinEff LinStd indBPint indBPlin);

! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
ResStd = ResEff   * SQRT(0.08077) / SQRT(8.3538);  ! STD WP Res effect
BPIntEff = ResEff + IntCont;                       ! WP + Context = BP int
IntStd = BPIntEff * SQRT(0.19530) / SQRT(18.0644); ! STD BP Int effect
BPLinEff = ResEff + LinCont;                       ! WP + Context = BP lin
LinStd = BPLinEff * SQRT(0.01049) / SQRT(0.48830); ! STD BP Slope effect
indBPint = XtoMint * BPIntEff;              ! BP intercept indirect effect
indBPlin = XtoMlin * BPLinEff;              ! BP age slope indirect effect
```

This is still an equivalent model, just with a different syntax for specifying the same level-1 WP residual to residual directed relationship. The consequence is that the intercept-to-intercept and slope-to-slope relationships become L2 contextual effects (as in the MLM version). Oddly, if we were to switch to ON for the intercept–slope cross-variable relationships, those stay L2 BP (see chapter 9 for an example using this version of the model).

Quadratic fixed effect for risky outcome not shown in diagram…



For balanced time, a linear growth model would look like this instead (add Mquad as third variable before |):

```
Mint Mlin | mon12@-6 mon13@-5 mon14@-4 mon15@-3
            mon16@-2 mon17@-1 mon18@0;
```

MODEL RESULTS – **changed parameters are in BOLD underline**

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Factor loadings set to 1 omitted				
RINT ON				
MINT	**-7.939**	**0.872**	**-9.099**	**0.000**
RLIN ON				
MLIN	**-5.294**	**0.806**	**-6.569**	**0.000**
RINT ON				
ATT4	-3.354	0.528	-6.348	0.000
RLIN ON				
ATT4	-0.512	0.105	-4.869	0.000
MINT ON				
ATT4	-0.044	0.057	-0.779	0.436
MLIN ON				
ATT4	0.003	0.014	0.240	0.810
RISKY12 ON				
MON12	3.559	0.301	11.810	0.000
RISKY13 ON				
MON13	3.559	0.301	11.810	0.000
RISKY14 ON				
MON14	3.559	0.301	11.810	0.000
RISKY15 ON				
MON15	3.559	0.301	11.810	0.000
RISKY16 ON				
MON16	3.559	0.301	11.810	0.000
RISKY17 ON				
MON17	3.559	0.301	11.810	0.000
RISKY18 ON				
MON18	3.559	0.301	11.810	0.000
RINT WITH				
RLIN	1.480	0.345	4.285	0.000
MLIN	0.039	0.038	1.023	0.306
MINT WITH				
MLIN	0.000	0.004	-0.105	0.916
RLIN	-0.107	0.031	-3.454	0.001
Means				
RQUAD	0.147	0.021	7.117	0.000
Intercepts				
Intercepts fixed to 0 omitted				
RINT	23.598	0.338	69.836	0.000
RLIN	1.969	0.139	14.195	0.000
MINT	0.063	0.034	1.839	0.066
MLIN	-0.003	0.008	-0.380	0.704
Variances				
RQUAD	0.000	0.000	999.000	999.000
Residual Variances				
RISKY12	7.329	0.328	22.353	0.000
RISKY13	7.329	0.328	22.353	0.000
RISKY14	7.329	0.328	22.353	0.000
RISKY15	7.329	0.328	22.353	0.000
RISKY16	7.329	0.328	22.353	0.000
RISKY17	7.329	0.328	22.353	0.000
RISKY18	7.329	0.328	22.353	0.000
MON12	0.081	0.004	22.354	0.000
MON13	0.081	0.004	22.354	0.000
MON14	0.081	0.004	22.354	0.000
MON15	0.081	0.004	22.354	0.000
MON16	0.081	0.004	22.354	0.000
MON17	0.081	0.004	22.354	0.000
MON18	0.081	0.004	22.354	0.000
RINT	14.315	2.030	7.053	0.000
RLIN	0.453	0.081	5.564	0.000
MINT	0.195	0.023	8.371	0.000
MLIN	0.010	0.001	7.802	0.000
New/Additional Parameters				
RESSTD	0.350	0.030	11.810	0.000
BPINTEFF	**-4.380**	**0.797**	**-5.496**	**0.000**
INTSTD	-0.455	0.083	-5.496	0.000
BPLINEFF	**-1.735**	**0.713**	**-2.434**	**0.015**
LINSTD	-0.254	0.104	-2.434	0.015
INDBPINT	0.194	0.251	0.772	0.440
INDBPLIN	-0.006	0.024	-0.239	0.811

By popular demand, here is an example of how to use "structured residuals" to fit two cross-lagged effects at level 1: Model 3a, which switches to covariances at level 2 when fitting these models (per convention, to be agnostic as to which comes first)

```
TITLE:  Model 3a: SEM Structured Residuals to Fit 2 Cross-Lag Paths
  ( DATA, VARIABLE, and ANALYSIS are the same as for Model 1 SEM )

MODEL:  ! R = risky behavior, M = monitoring
[risky12-risky18@0 mon12-mon18@0]; ! All variable intercepts fixed to 0

! Risky behavior quadratic growth model using exact age as loadings
  Rint Rlin Rquad | risky12-risky18 AT age12-age18;
! Monitoring linear growth model using exact age as loadings
  Mint Mlin | mon12-mon18 AT age12-age18;
! Fixed growth effects for R and M
  [Rint Rlin Rquad Mint Mlin];
! L2 G: Random int and linear age slope variances, no quad age variance
  Rint Rlin Mint Mlin (Rintvar Rlinvar Mintvar Mlinvar); Rquad@0;
! Attitudes --> R int, R linear slope, M int, M linear slope
  Rint Rlin Mint Mlin ON att4 (XtoYint XtoYlin XtoMint XtoMlin);
! L2 G: covariances for random intercepts and slopes across outcomes
  Rint Rlin Mint Mlin WITH Rint Rlin Mint Mlin;

! Define new latent factors for residuals at each occasion
  Frisky12 BY risky12@1; Frisky13 BY risky13@1; Frisky14 BY risky14@1;
  Frisky15 BY risky15@1; Frisky16 BY risky16@1; Frisky17 BY risky17@1;
  Frisky18 BY risky18@1; Fmon12 BY mon12@1; Fmon13 BY mon13@1;
  Fmon14 BY mon14@1; Fmon15 BY mon15@1; Fmon16 BY mon16@1;
  Fmon17 BY mon17@1; Fmon18 BY mon18@1;
! All factor means fixed to 0
  [Frisky12-Frisky18@0 Fmon12-Fmon18@0];
! Shut off old residual variances
  risky12-risky18@0 mon12-mon18@0;
! Hold new residual variances equal over time if predicted
  Frisky13-Frisky18 (Rresvar); ! L1 R: R residual variances held equal
  Fmon13-Fmon18     (Mresvar); ! L1 R: M residual variances held equal

! Factor residual WP covariance between same ages
  Frisky12 WITH Fmon12;
! Predicted occasions held equal across age
  Frisky13-Frisky18 PWITH Fmon13-Fmon18 (ResCov);

! Cross-lagged WP effects predicting next age, held equal across age
  Frisky13-Frisky18 PON Fmon12-Fmon17     (MR2RR);
  Fmon13-Fmon18     PON Frisky12-Frisky17 (RR2MR);

MODEL CONSTRAINT:
NEW(MR2RRsd RR2MRsd);
! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  MR2RRsd = MR2RR * SQRT(0.08077) / SQRT(8.3538);  ! STD M->R lag effect
  RR2MRsd = RR2MR * SQRT(8.3538)  / SQRT(0.08077); ! STD R->M lag effect
```

This is NOT an equivalent model given the two new cross-lagged effects, along with the two separate residual variances and covariance for age 12.

MODEL RESULTS – Parameters fixed to 0 or 1 are omitted for brevity

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
FRISKY13 ON				
FMON12	-0.171	0.368	-0.465	0.642
FRISKY14 ON				
FMON13	-0.171	0.368	-0.465	0.642
FRISKY15 ON				
FMON14	-0.171	0.368	-0.465	0.642
FRISKY16 ON				
FMON15	-0.171	0.368	-0.465	0.642
FRISKY17 ON				
FMON16	-0.171	0.368	-0.465	0.642
FRISKY18 ON				
FMON17	-0.171	0.368	-0.465	0.642
FMON13 ON				
FRISKY12	0.008	0.004	2.131	0.033
FMON14 ON				
FRISKY13	0.008	0.004	2.131	0.033
FMON15 ON				
FRISKY14	0.008	0.004	2.131	0.033
FMON16 ON				
FRISKY15	0.008	0.004	2.131	0.033
FMON17 ON				
FRISKY16	0.008	0.004	2.131	0.033
FMON18 ON				
FRISKY17	0.008	0.004	2.131	0.033
RINT ON				
ATT4	-3.153	0.552	-5.713	0.000
RLIN ON				
ATT4	-0.514	0.105	-4.877	0.000
MINT ON				
ATT4	-0.043	0.057	-0.765	0.444
MLIN ON				
ATT4	0.004	0.014	0.309	0.757
RINT WITH				
RLIN	1.945	0.363	5.365	0.000
MINT	-0.884	0.170	-5.213	0.000
MLIN	0.038	0.039	0.976	0.329
RLIN WITH				
MINT	-0.110	0.031	-3.511	0.000
MLIN	-0.018	0.008	-2.375	0.018
MINT WITH				
MLIN	-0.001	0.004	-0.310	0.756

```
 FRISKY12 WITH
    FMON12             0.053      0.087      0.608      0.543

 FRISKY13 WITH
    FMON13             0.329      0.033      9.970      0.000

 FRISKY14 WITH
    FMON14             0.329      0.033      9.970      0.000

 FRISKY15 WITH
    FMON15             0.329      0.033      9.970      0.000

 FRISKY16 WITH
    FMON16             0.329      0.033      9.970      0.000

 FRISKY17 WITH
    FMON17             0.329      0.033      9.970      0.000

 FRISKY18 WITH
    FMON18             0.329      0.033      9.970      0.000

Means
    RQUAD              0.145      0.021      7.041      0.000
 Intercepts
    RINT              23.322      0.347     67.162      0.000
    RLIN               1.971      0.137     14.378      0.000
    MINT               0.064      0.034      1.873      0.061
    MLIN              -0.003      0.008     -0.326      0.745

Variances
    FRISKY12           9.010      1.277      7.055      0.000
    FMON12             0.061      0.011      5.372      0.000
    RQUAD              0.000      0.000    999.000    999.000

 Residual Variances
    FRISKY13           8.188      0.395     20.711      0.000
    FRISKY14           8.188      0.395     20.711      0.000
    FRISKY15           8.188      0.395     20.711      0.000
    FRISKY16           8.188      0.395     20.711      0.000
    FRISKY17           8.188      0.395     20.711      0.000
    FRISKY18           8.188      0.395     20.711      0.000
    FMON13             0.084      0.004     20.580      0.000
    FMON14             0.084      0.004     20.580      0.000
    FMON15             0.084      0.004     20.580      0.000
    FMON16             0.084      0.004     20.580      0.000
    FMON17             0.084      0.004     20.580      0.000
    FMON18             0.084      0.004     20.580      0.000
    RINT              18.257      2.213      8.249      0.000
    RLIN               0.513      0.083      6.180      0.000
    MINT               0.191      0.023      8.259      0.000
    MLIN               0.010      0.001      7.859      0.000

New/Additional Parameters
    MR2RRSD           -0.017      0.036     -0.465      0.642
    RR2MRSD            0.079      0.037      2.131      0.033
```

What if we controlled for the concurrent effect of M → before examining the lagged effect of Monitor → Risky (my own preference)?

```
TITLE:  Model 3b: Example of Structured Residuals to Fit M->R Cross-Lagged
Path that controls for concurrent effect before fitting the lagged effect
```

All else is the same until here…

```
! Factor residual WP effect between same ages, held equal across age
  Frisky12-Frisky18 PON Fmon12-Fmon18 (ResEff);

! Cross-lag WP effects predicting next age, held equal across age
  Frisky13-Frisky18 PON Fmon12-Fmon17 (MR2RR);

MODEL CONSTRAINT:
NEW(ResStD MR2RRsd);
! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  ResStD = ResEff * SQRT(Mresvar) / SQRT(Rresvar);  ! STD M->R concurrent
  MR2RRsd = MR2RR * SQRT(Mresvar) / SQRT(Rresvar);  ! STD M->R lagged effect
```

```
                                                    Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value
New/Additional Parameters
    RESSTD             0.339      0.031     10.952      0.000
    MR2RRSD           -0.054      0.033     -1.610      0.107
```

```
TITLE:  Model 3c: Example of Structured Residuals to Fit R->M Cross-Lagged
Path that controls for concurrent effect before fitting the lagged effect
```

All else is the same until here…

```
! Factor residual WP effect between same ages, held equal across age
  Fmon12-Fmon18 PON Frisky12-Frisky18 (ResEff);

! Cross-lag WP effects predicting next age, held equal across age
  Fmon13-Fmon18 PON Frisky12-Frisky17 (RR2MR);

MODEL CONSTRAINT:
NEW(ResStD RR2MRsd);
! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  ResStD = ResEff * SQRT(8.3538) / SQRT(0.08077); ! STD R->M concurrent
  RR2MRsd = RR2MR * SQRT(8.3538) / SQRT(0.08077); ! STD R->M lagged effect
```

```
                                                    Two-Tailed
                    Estimate       S.E.  Est./S.E.    P-Value
New/Additional Parameters
    RESSTD             0.371      0.031     11.846      0.000
    RR2MRSD            0.087      0.034      2.547      0.011
```

It looks like evidence for a lagged Risky → Monitor lagged effect is a little stronger after controlling for the concurrent effect (and vice-versa).

Here is a comparison of the SEM cross-lagged effects to those from MLM using MLM using the LAGGED residual option (available in Mplus 8.1+ with BAYES estimation).

```
TITLE:   Model 3a: Undirected Directed Multivariate Growth Model as MLM
         All fixed L1 effects specified in WITHIN
         Adding lagged effects of both M -> R and R --> M
         using new residual LAGGED option and BAYES estimation

DATA:    FILE = Example3.csv;    ! Syntax in same folder as data
VARIABLE: ! List of variables in data file
  NAMES = PersonID Att12 occasion age risky mon roundage
          time att4 timesq mon3;
! Variables to be analyzed in this model
  USEVARIABLE = time timesq att4 risky mon3;
  MISSING ARE ALL (-999);    ! Missing data identifier
! MLM options
  CLUSTER = PersonID;             ! Level-2 ID
  BETWEEN = att4;                 ! Observed ONLY level-2 predictors
  WITHIN  = time timesq;          ! Observed ONLY level-1 predictors
  LAGGED  = risky(1) mon3(1);     ! Create Mplus lag-1 variables

ANALYSIS:    TYPE = TWOLEVEL RANDOM; ESTIMATOR = BAYES; BITERATIONS = 50000;
ANALYSIS:    TECH8;  ! Used to examined convergence
MODEL:   ! R = risky behavior, M = monitoring
%WITHIN%
 risky mon3 (Rresvar Mresvar); ! L1 R: Residual variances (labels)
 Rlin  | risky ON time;        ! Placeholder for R linear age slope
 Rquad | risky ON timesq;      ! Placeholder for R quadratic age slope
 Mlin  | mon3  ON time;        ! Placeholder for M linear age slope
 risky WITH mon3    (ResCov);  ! L1 WP covariance for concurrent M->R
 risky^ ON mon3^1   (MRLagEff); ! L1 WP fixed effect of ^residual lagged M->R
 mon3^  ON risky^1  (RMLagEff); ! L1 WP fixed effect of ^residual lagged R->M

%BETWEEN%
[risky mon3 Rlin Rquad Mlin];  ! Fixed intercepts, slopes
 risky mon3 (Rintvar Mintvar); ! L2 G: Random intercept variances (labels)
 Rlin Mlin  (Rlinvar Mlinvar); ! L2 G: Random linear age slope variances
 risky Rlin ON att4 (XtoYint XtoYlin);  ! Att-> R int, linear age slope
  mon3 Mlin ON att4 (XtoMint XtoMlin);  ! Att-> M int, linear age slope
! L2 G: covariances for random intercepts and slopes across outcomes
  risky Rlin mon3 Mlin WITH risky Rlin mon3 Mlin;
 Rquad@0;                       ! No quadratic age slope variance

MODEL CONSTRAINT:
NEW(ResCor MR2RRsd RR2MRsd);
! Corr = Cov / (SQRT(Yvar)*SQRT(Xvar))
  ResCor = ResCov / (SQRT(8.3538)*SQRT(0.08077));
! STD = Unstd * SQRT(Xvar) / SQRT(Yvar)
  MR2RRsd = MRLagEff * SQRT(0.08077) / SQRT(8.3538);  ! STD M->R lagged effect
  RR2MRsd = RMLagEff * SQRT(8.3538)  / SQRT(0.08077); ! STD R->M lagged effect
```

Note that this Model 3a is not fully equivalent to the SEM version—it constrains the level-1 residual variances and same-occasion covariance to be equal over time (even though the age 12 versions are unpredicted).

3a SEM via ML and its lagged effects

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value	
RESCOR	0.363	0.031	11.624	0.000	*
MR2RRSD	-0.025	0.037	-0.681	0.496	
RR2MRSD	0.077	0.037	2.083	0.037	*

3a MLM via Bayes and their residual lagged effects

	Estimate	Posterior S.D.	One-Tailed P-Value	Significance
New/Additional Parameters				
RESCOR	0.369	0.037	0.000	*
MR2RRSD	-0.017	0.037	0.303	
RR2MRSD	0.081	0.036	0.013	*

Activity: Try the following sequential model modifications of Model 3a in both the SEM and MLM syntax versions of Mplus

1. **Change the concurrent level-1 covariance to become a fixed slope for risky → monitoring and remove the level-1 lagged effect of monitoring → risky. What impact does this have on the lagged effect of monitoring → risky?**

2. **Fit a random slope for the concurrent effect of risky → monitoring and its covariances with the other random effects. What conclusions can you draw?**