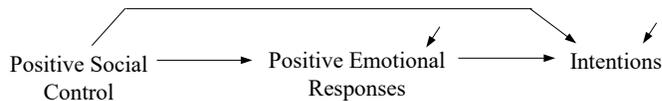


Path Analysis Example

A simple path model with test of the indirect effect coefficient is illustrated with Mplus and the lavaan R package below. The hypothesis is that positive social control (*pc*; efforts to directly encourage healthy behavior by social network members) causes positive emotional responses (*pleased*), which, in turn, causes more intention to engage in physical activity (*intent*). This hypothesis was reported in a prior paper (Newsom, Shaw, August, & Strath, 2018), but please note that the results in this example no longer hold when other related variables are included, latent variables are used, and there is a more complicated relationship of social support, social control, behavioral intentions to physical activity behavior.



The tests of the indirect effect use the percentile bootstrap confidence interval approach, which will generally produce preferable confidence limits and standard errors for the indirect effect test (Biesanz, Falk, & Savalei, 2010; Chen & Fritz, 2021; Falk & Biesanz, 2015; Fritz, Taylor, & MacKinnon, 2012; Tofighi and MacKinnon, 2016; Valente, Gonzalez, Miočević, & MacKinnon, 2016). See the aforementioned references or the handout “Testing Mediation with Regression Analysis” on my SEM course site. The examples below illustrate using standard maximum likelihood with no missing data. In practice, missing data are likely to be present and I usually recommend missing data estimation with a full maximum likelihood estimation approach and robust standard errors for the direct effects (see later handouts for this course, “Missing Data and Missing Data Estimation in SEM” and “SEM with Nonnormal Continuous Variables”).

Mplus (output excerpts)

```

Mplus VERSION 8.9
MUTHEN & MUTHEN

INPUT INSTRUCTIONS

  title:  Data from social control pilot study (no missing data);

  data:  file=controlpath1.dat;  format=free;

  variable:  names = pc pleased intent;

  analysis:  type=general;  estimator=ml;
  ! we will eventually change estimator, default is for robust and missing;
  ! covariance matrix is estimated by default;
  bootstrap = 1000;
  ! at least 500 bootstrap samples are recommended;

  model:  pleased on pc;
         intent on pc pleased;

  ! the following command estimates the indirect path coefficient and tests;
  Model indirect:  intent ind pc;

  ! cinterval (bootstrap) gives percentile bootstrap confidence intervals.
  output:  stdyx cinterval(bootstrap);

INPUT READING TERMINATED NORMALLY
THE MODEL ESTIMATION TERMINATED NORMALLY

MODEL FIT INFORMATION
Number of Free Parameters          7

Loglikelihood

      H0 Value          -426.060
      H1 Value          -426.060
  
```

MODEL RESULTS

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
PLEASED ON PC	0.198	0.063	3.151	0.002
INTENT ON PC	0.075	0.034	2.207	0.027
PLEASED PLEASED	0.306	0.069	4.411	0.000
Intercepts PLEASED	1.976	0.094	21.044	0.000
INTENT	3.715	0.176	21.159	0.000
Residual Variances PLEASED	0.763	0.072	10.626	0.000
INTENT	0.347	0.065	5.375	0.000

STANDARDIZED MODEL RESULTS

STDYX Standardization

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
PLEASED ON PC	0.221	0.075	2.943	0.003
INTENT ON PC	0.113	0.050	2.261	0.024
PLEASED PLEASED	0.414	0.076	5.485	0.000
Intercepts PLEASED	2.207	0.184	11.976	0.000
INTENT	5.621	0.836	6.724	0.000
Residual Variances PLEASED	0.951	0.033	28.869	0.000
INTENT	0.795	0.057	13.833	0.000

R-SQUARE

Observed Variable	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
PLEASED	0.049	0.033	1.482	0.138
INTENT	0.205	0.057	3.566	0.000

TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Effects from PC to INTENT Total	0.135	0.036	3.772	0.000
Total indirect	0.061	0.025	2.462	0.014
Specific indirect 1 INTENT PLEASED PC	0.061	0.025	2.462	0.014
Direct INTENT PC	0.075	0.034	2.207	0.027

STANDARDIZED TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

STDYX Standardization

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
Effects from PC to INTENT Total	0.204	0.050	4.049	0.000
Total indirect	0.092	0.036	2.562	0.010

Specific indirect 1				
INTENT				
PLEASED				
PC	0.092	0.036	2.562	0.010
Direct				
INTENT				
PC	0.113	0.050	2.261	0.024

CONFIDENCE INTERVALS OF MODEL RESULTS

	Lower .5%	Lower 2.5%	Lower 5%	Estimate	Upper 5%	Upper 2.5%	Upper .5%
PLEASED ON							
PC	-0.018	0.061	0.085	0.198	0.294	0.311	0.349
INTENT ON							
PC	-0.005	0.011	0.023	0.075	0.132	0.148	0.167
PLEASED	0.140	0.174	0.196	0.306	0.425	0.448	0.486
Intercepts							
PLEASED	1.730	1.794	1.826	1.976	2.127	2.159	2.229
INTENT	3.247	3.349	3.418	3.715	4.000	4.032	4.112
Residual Variances							
PLEASED	0.582	0.615	0.633	0.763	0.871	0.893	0.950
INTENT	0.190	0.223	0.242	0.347	0.454	0.475	0.529

CONFIDENCE INTERVALS OF STANDARDIZED MODEL RESULTS

STDYX Standardization							
	Lower .5%	Lower 2.5%	Lower 5%	Estimate	Upper 5%	Upper 2.5%	Upper .5%
PLEASED ON							
PC	-0.019	0.066	0.092	0.221	0.342	0.361	0.398
INTENT ON							
PC	-0.009	0.019	0.032	0.113	0.200	0.213	0.244
PLEASED	0.199	0.258	0.289	0.414	0.532	0.550	0.578
Intercepts							
PLEASED	1.769	1.888	1.932	2.207	2.548	2.596	2.719
INTENT	3.942	4.292	4.479	5.621	7.159	7.491	8.101
Residual Variances							
PLEASED	0.834	0.868	0.883	0.951	0.991	0.995	1.000
INTENT	0.637	0.672	0.687	0.795	0.878	0.890	0.921

CONFIDENCE INTERVALS OF TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

	Lower .5%	Lower 2.5%	Lower 5%	Estimate	Upper 5%	Upper 2.5%	Upper .5%
Effects from PC to INTENT							
Total	0.041	0.069	0.078	0.135	0.199	0.210	0.243
Total indirect	-0.006	0.017	0.023	0.061	0.103	0.115	0.137
Specific indirect 1							
INTENT							
PLEASED							
PC	-0.006	0.017	0.023	0.061	0.103	0.115	0.137
Direct							
INTENT							
PC	-0.005	0.011	0.023	0.075	0.132	0.148	0.167

CONFIDENCE INTERVALS OF STANDARDIZED TOTAL, TOTAL INDIRECT, SPECIFIC INDIRECT, AND DIRECT EFFECTS

STDYX Standardization							
	Lower .5%	Lower 2.5%	Lower 5%	Estimate	Upper 5%	Upper 2.5%	Upper .5%

Effects from PC to INTENT

Total	0.053	0.100	0.126	0.204	0.288	0.305	0.327
Total indirect	-0.008	0.025	0.035	0.092	0.152	0.165	0.202
Specific indirect 1							
INTENT							
PLEASED							
PC	-0.008	0.025	0.035	0.092	0.152	0.165	0.202
Direct							
INTENT							
PC	-0.009	0.019	0.032	0.113	0.200	0.213	0.244

Significance of the indirect effect should be based on the confidence intervals for the unstandardized effects.

R

```
> library(lavaan)
>
> # note that all the lavaan model commands are enclosed single quotes
> model = '
+ intent ~ c*pc
+ pleased ~ a*pc
+ intent ~ b*pleased
+ #indirect effect
+   ab := a*b
+
+ #total effect
+ total := c + (a*b)
+ '
> #use for mediation model (at least 500 bootstrap samples usually recommended)
>
> fit = sem(model, data = path1, se = 'bootstrap', bootstrap = 1000)
> summary(fit, fit.measures=TRUE, rsquare=TRUE, standardized=TRUE)
```

Output excerpts

lavaan 0.6.15 ended normally after 1 iteration

```
Estimator              ML
Optimization method    NLMINB
Number of model parameters 5

Number of observations 196
```

Parameter Estimates:

```
Standard errors      Bootstrap
Number of requested bootstrap draws 1000
Number of successful bootstrap draws 1000
```

Regressions:

		Estimate	Std.Err	z-value	P(> z)	Std.lv	Std.all
intent ~							
pc	(c)	0.075	0.035	2.106	0.035	0.075	0.113
pleased ~							
pc	(a)	0.198	0.063	3.131	0.002	0.198	0.221
intent ~							
pleased	(b)	0.306	0.068	4.500	0.000	0.306	0.414

Variances:

	Estimate	Std.Err	z-value	P(> z)	Std.lv	Std.all
.intent	0.347	0.066	5.255	0.000	0.347	0.795
.pleased	0.763	0.076	10.039	0.000	0.763	0.951

R-Square:

	Estimate
intent	0.205
pleased	0.049

Defined Parameters:

	Estimate	Std.Err	z-value	P(> z)	Std.lv	Std.all
ab	0.061	0.024	2.547	0.011	0.061	0.092
total	0.135	0.035	3.889	0.000	0.135	0.204

```
> parameterEstimates(fit, ci = TRUE, boot.ci.type = "perc", level = 0.95, standardized = TRUE)
  lhs op      rhs label  est   se      z pvalue ci.lower ci.upper std.lv std.all std.nox
1 intent ~      pc      c 0.075 0.035  2.106 0.035  0.006  0.148 0.075  0.113  0.113
2 pleased ~      pc      a 0.198 0.063  3.131 0.002  0.063  0.315 0.198  0.221  0.221
3 intent ~ pleased b 0.306 0.068  4.500 0.000  0.177  0.440 0.306  0.414  0.414
4 intent ~ intent 0.347 0.066  5.255 0.000  0.226  0.494 0.347  0.795  0.795
5 pleased ~ pleased 0.763 0.076 10.039 0.000  0.609  0.905 0.763  0.951  0.951
6 pc ~      pc      1.000 0.000      NA      NA  1.000  1.000 1.000  1.000  1.000
7 ab :=      a*b     ab 0.061 0.024  2.547 0.011  0.019  0.114 0.061  0.092  0.092
8 total := c+(a*b) total 0.135 0.035  3.889 0.000  0.066  0.204 0.135  0.204  0.204
```

The sample write-up used the results from the Mplus output. Note that because the indirect effect confidence limits are based on bootstrap estimation, which involves random draws, the programs (or even different runs) will lead to slightly different values.

Sample write-up:

To investigate whether positive emotional responses mediate the relation between positive social control and intention to engage in physical activity, a path model was tested using Mplus Version 8.9 (Muthén & Muthén, 1998-2017).¹ Results indicated that positive social control predicted positive emotional responses, $\beta = .198$, $SE = .063$, $\beta^* = .221$, $p = .002$, and that positive emotional responses predicted intentions, $\beta = .306$, $SE = .069$, $\beta^* = .414$, $p < .001$. The indirect effect, tested using percentile bootstrapped confidence intervals (Shrout & Bolger, 2002), also was significant, $\beta = .061$, 95% CI[.017, .115], $\beta^* = .092$). The direct effect of positive social control on intentions remained significant after positive emotional responses was controlled, $\beta = .075$, $SE = .034$, $\beta^* = .113$, $p = .027$, suggesting that the significant indirect effect is consistent only with a partial mediational effect. The total amount of variance in intentions accounted for by positive control and positive emotional responses was approximate 20%, $R^2 = .205$.

References

- Biesanz, J. C., Falk, C. F., & Savalei, V. (2010). Assessing mediational models: Testing and interval estimation for indirect effects. *Multivariate Behavioral Research*, 45, 661–701. <http://dx.doi.org/10.1080/00273171.2010.498292>
- Chen, D., & Fritz, M. S. (2021). Comparing alternative corrections for bias in the bias-corrected bootstrap test of mediation. *Evaluation & The Health Professions*, 44(4), 416-427.
- Falk, C. F., & Biesanz, J. C. (2015). Inference and interval estimation methods for indirect effects with latent variable models. *Structural Equation Modeling: A Multidisciplinary Journal*, 22(1), 24-38.
- Fritz, M. S., Taylor, A. B., & MacKinnon, D. P. (2012). Explanation of two anomalous results in statistical mediation analysis. *Multivariate Behavioral Research*, 47(1), 61-87.
- Muthén, L.K. and Muthén, B.O. (1998-2017). *Mplus User's Guide. Eight Edition*. Los Angeles, CA: Muthén & Muthén.
- Newsom, J. T., Shaw, B. A., August, K. J., & Strath, S. J. (2018). Physical activity-related social control and social support in older adults: Cognitive and emotional pathways to physical activity. *Journal of Health Psychology*, 23(11), 1389-1404.
- Shrout, P.E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, 7, 422-445.
- Tofighi, D., & MacKinnon, D. P. (2016). Monte Carlo confidence intervals for complex functions of indirect effects. *Structural Equation Modeling: A Multidisciplinary Journal*, 23(2), 194-205.
- Valente, M. J., Gonzalez, O., Miočević, M., & MacKinnon, D. P. (2016). A note on testing mediated effects in structural equation models: Reconciling past and current research on the performance of the test of joint significance. *Educational and Psychological Measurement*, 76(6), 889-911.

¹ The citation for the software and the bootstrap approach is probably typically reported in the general description of the analysis (e.g., "Analysis Overview") appearing in the end of the Methods or beginning of the Analysis section. These preliminary sections would also report the number of bootstrap samples that were used (here, I used 1,000).