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Hambrick. The impact of domain-specific experience on chess skill: Re-analysis of a key study

Results for current rating after Expectation-Maximization imputation of missing data

The training variables that had the highest correlations with current rating were peak study time ($r = .57, p < .001$) and books ($r = .56, p < .001$). Serious age was negatively correlated with current rating ($r = -.40, p < .001$). Players who started playing chess seriously at an early age tended to reach a higher level of skill than players who started at a later age.

Exploratory Factor Analyses

We used EFA to investigate the factor structure of predictors of current rating. Predictors of current rating included total study time, total tournament time, books, total private instruction, and total group instruction.

We performed the EFA using principal axis extraction. The criterion for factor extraction was an eigenvalue greater than 1.0, and we rotated the factors with an oblique rotation procedure (Promax) to allow any factors that emerged to correlate. Results are presented in Table S1. The analysis for predictors of current rating yielded two factors. The first factor, which we label Serious Chess Activity, had high loadings on the following variables: total study time, total tournament time, and books. The second factor, which we label Chess Instruction, had high loadings on the following variables: total private

instruction and total group instruction. For the predictors of current rating, the correlation between the two factors was $r = .40$.

Structural Equation Modeling

One goal of this study was to assess how much of the variance in current rating could be accounted for by domain-specific experience. We used SEM to address this goal. Two steps were involved. Guided by the results of the EFA, the first step was to perform confirmatory factor analyses (CFA) on predictors of current rating. We specified two factors in each CFA: Serious Chess Activity and Chess Instruction (the factor-indicator correspondences were identical to those from the EFA). Model fit was good for the current rating model, $\chi^2(4) = 17.31, p < .01, CFI = .96, NFI = .95, RMSEA = .09$.

Table S1. *Summary of exploratory factor analysis results for predictors of current rating (listwise N = 377)*

Variable	Serious Chess Activity	Chess Instruction
Total study time	1.00	-.10
Total tournament play	.59	.07
Books	.44	.23
Total private instruction	.12	.44
Total group instruction	-.03	.69
Eigenvalues	2.27	1.03
% of variance	45.41	20.61

Note: Factor loadings $\geq .40$ appear in bold.

The second step in the SEM was to assess the effect of Serious Chess Activity and Chess Instruction, along with serious starting age, on current rating. Results are illustrated in Figure S1. Serious Chess Activity had a significant positive effect on rating ($.53, p < .001$), whereas the effect of Chess Instruction was near zero ($.19, p > .05$). Furthermore, serious starting age had a significant negative effect on rating ($-.22, p < .01$), above and beyond the chess experience factors. Collectively, the model accounted for 55.3% of the variance in

current rating. Model fit was acceptable, $\chi^2(10) = 60.18, p < .001, CFI = .93, NFI = .91,$
 RMSEA = .12.

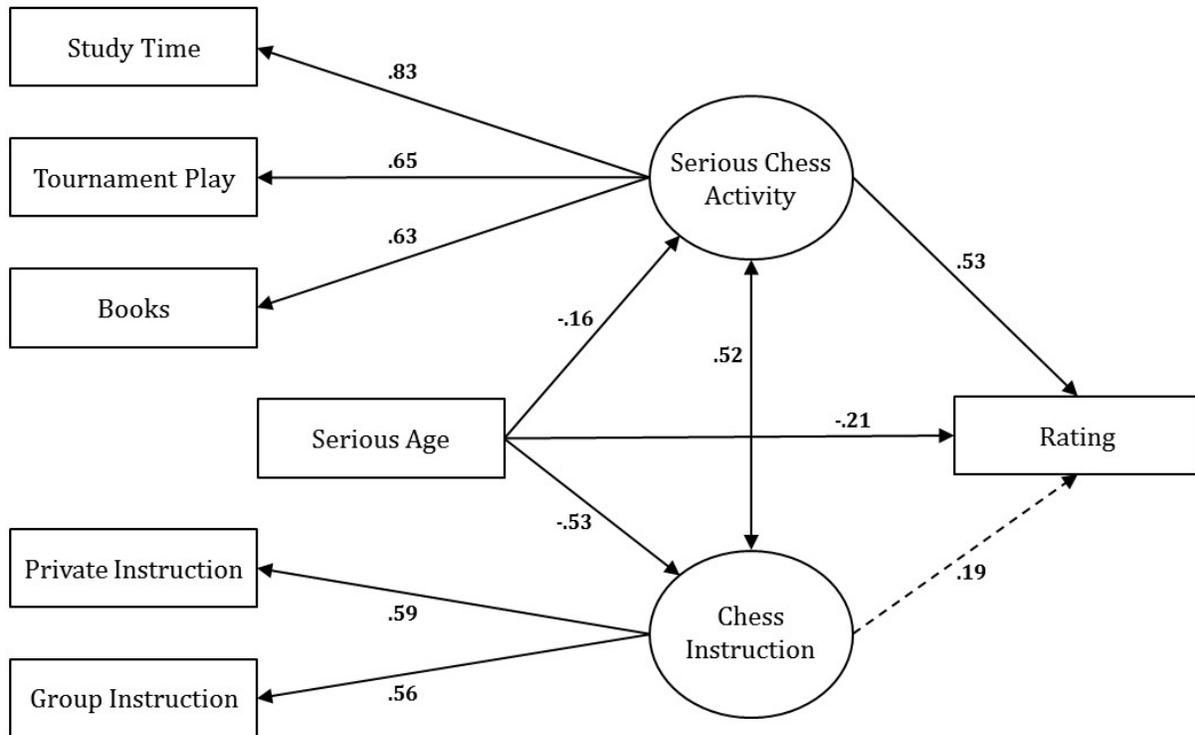


Figure S1. Structural equation model predicting current rating (listwise $n = 377$).

Additional Analyses

Competition experience. We used hierarchical multiple regression to examine whether competition experience (i.e., total tournament play) contributed to the prediction of current rating above and beyond the expected contribution of serious study and formal instruction. We entered total study time, total private instruction, and total group instruction in Step 1 of the model and total tournament play in Step 2 of the model.

The overall model accounted for 36.3% of the variance in current rating, $F(4, 372) = 53.06, SEE = 221, p < .001$ (Table S2). Tournament play did not significantly contribute to

the prediction of current rating above and beyond study time and formal instruction, $\Delta R^2 = .00, p > .05$.

Table S2. Hierarchical regression of current rating on deliberate practice and other predictor variables for tournament-rated chess players ($N = 377$)

	ΔR^2	Sig. F Change	B	β	t
Step 1	.36	< .001			
Total study time			238.5	.44	8.38***
Total private instruction			187.7	.23	5.22***
Total group instruction			81.5	.12	2.60**
Step 2	.00	> .05			
Total tournament play			13.6	.02	0.46

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Serious study and formal instruction. We used multiple regression to test the hypothesis that the effect of serious study on current rating was moderated by formal instruction such as private lessons and group lessons. We also tested whether serious study was moderated by chess books, another training aid. We took standardized scores for current study time, current private instruction, current group instruction, and books, and computed Current Study Time \times Current Private Instruction, Current Study Time \times Current Group Instruction, and Current Study Time \times Books interaction terms (Aiken, West & Reno, 1991). Next, we entered current study time, current tournament play, current private instruction, current group instruction, books, and serious starting age in Step 1 of the model, and the preceding interaction terms in Step 2.

The overall model accounted for 50.7% of the variance in current rating, $F(9, 367) = 41.98, SEE = 196, p < .001$ (Table S3). The interaction terms did not contribute significantly to the prediction of current rating, $\Delta R^2 = .005, p = .33$.

Table S3. Hierarchical regression of current rating on predictor variables for tournament-rated chess players ($N = 377$)

	ΔR^2	Sig. F Change	B	β	t
Step 1	.50	.00			
Total study time			153.8	.28	5.67***
Total tournament play			18.6	.03	0.71
Total private instruction			161.9	.20	4.32***
Total group instruction			-4.1	-.01	-0.14
Books			159.8	.30	6.92***
Serious age			-8.2	-.26	-6.28***
Step 2	.005	.33			
Study \times Private Instruction			-17.9	-.07	-1.50
Study \times Group Instruction			4.4	.02	0.39
Study \times Books			-6.3	-.02	-0.64

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Age subsets. We conducted multiple regression analyses on predictors of current rating for older (age ≥ 44) and younger (age < 44) chess players (Table S4). For older chess players, the model accounted for 54.3% of the variance in current rating, $F(6, 95) = 18.84$, $SEE = 186$, $p < .001$. For younger chess players, the model accounted for 51.0% of the variance in current rating, $F(6, 219) = 38.05$, $SEE = 190$, $p < .001$. For younger chess players, study time, private instruction, books, and serious age were significant predictors of current rating. For older chess players, only study time and books were significant predictors of current rating.

Table S4. Hierarchical regression of current rating on predictor variables for younger (age < 44) and older (age ≥ 44) tournament-rated chess players.

	Younger (n = 226)				Older (n = 102)			
	R ²	B	β	t	R ²	B	β	t
Step 1	.51				.54			
Peak study time		182.2	.34	5.59***		205.8	.35	3.78***
Peak tournament play		38.8	.06	1.10		91.7	.14	1.67
Peak private instruction		114.2	.14	2.72**		73.0	.09	1.17
Peak group instruction		0.0	.00	0.00		-44.5	-.07	-0.89
Books		161.1	.30	5.46***		184.7	.37	4.54***
Serious age		-9.6	-.17	-2.96**		-2.6	-.11	-1.45

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B, unstandardized regression coefficient; β, standardized regression coefficient.

Results for subjects with no missing values

Table S5 displays the descriptive statistics and correlations for chess skill, training activities, and age variables for the combined samples. The training variables that had the highest correlations with peak rating and current rating were peak study time ($r_s = .57$ and $.56$, $p_s < .001$) and books ($r_s = .57$ and $.55$, $p_s < .001$). Serious age was negatively correlated with peak rating and current rating ($r_s = -.33$ and $-.34$, $p_s < .001$). Players who started playing chess seriously at an early age tended to reach a higher level of skill than players who started at a later age. Peak rating and current rating were highly correlated ($r = .96$, $p < .001$).

Exploratory Factor Analyses

We used EFA to investigate the factor structure of two sets of variables: (1) predictors of peak rating, and (2) predictors of current rating. Predictors of peak rating included peak study time, peak tournament time, books, peak private instruction, and peak group instruction. Predictors of current rating included total study time, total tournament time, books, total private instruction, and total group instruction.

We performed a separate EFA for each set of variables (principal axis extraction). The criterion for factor extraction was an eigenvalue greater than 1.0, and we rotated the factors with an oblique rotation procedure (Promax) to allow any factors that emerged to correlate. Results are presented in Tables S6 and S7. The analyses for predictors of peak rating and predictors of current rating both yielded two factors. The first factor, which we label Serious Chess Activity, had high loadings on the following variables: peak/total study

time, peak/total tournament time, and books. The second factor, which we label Chess Instruction, had high loadings on the following variables: peak/total private instruction and peak/total group instruction. For the predictors of peak rating, the correlation between the two factors was $r = .42$; for the predictors of current rating, the correlation between the two factors was $r = .42$.

Structural Equation Modeling

The focus of this study was to assess how much of the variance in peak rating and current rating could be accounted for by domain-specific experience. We used SEM to address this goal. Two steps were involved. Guided by the results of the EFA, the first step was to perform confirmatory factor analyses (CFA) on predictors of peak rating and predictors of current rating. We specified two factors in each CFA: Serious Chess Activity and Chess Instruction (the factor-indicator correspondences were identical to those from the EFA). Model fit was good for both the peak rating model, $\chi^2(4) = 12.76, p < .05, CFI = .97, NFI = .96, RMSEA = .08$, and for the current rating model, $\chi^2(4) = 14.52, p < .01, CFI = .97, NFI = .95, RMSEA = .09$.

Table S5. Correlations and descriptive statistics for chess skill, activities, and age variables. (listwise N = 328)

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Peak rating		.96	.57	.57	.44	.41	.35	.35	.29	.29	.57	-.33
2. Current rating			.56	.53	.43	.36	.36	.36	.27	.26	.55	-.34
3. Peak study time				.91	.59	.51	.24	.23	.17	.17	.45	-.11
4. Total study time					.52	.59	.24	.25	.19	.18	.47	-.07
5. Peak tournament play						.85	.17	.17	.19	.19	.33	-.09
6. Total tournament play							.16	.16	.22	.22	.35	-.04
7. Peak private instruction								1.00	.33	.32	.23	-.25
8. Total private instruction									.33	.32	.23	-.25
9. Peak group instruction										1.00	.26	-.34
10. Total group instruction											.27	-.34
11. Books												-.18
12. Serious age												
Mean	2084	2036	3.40	3.51	3.46	3.55	0.18	0.18	0.35	0.36	1.74	15.5
SD	260	269	0.52	0.51	0.46	0.47	0.33	0.33	0.39	0.39	0.52	7.92

Note: Coefficients in bold are statistically significant at $p < 0.01$.

Table S6. *Summary of exploratory factor analysis results for predictors of peak rating (listwise N = 328)*

Variable	Serious Chess Activity	Chess Instruction
Peak study time	.95	-.08
Peak tournament play	.63	.03
Books	.41	.23
Peak private instruction	.09	.45
Peak group instruction	-.04	.69
Eigenvalues	2.22	1.06
% of variance	44.31	21.10

Note: Factor loadings $\geq .40$ appear in bold.

Table S7. *Summary of exploratory factor analysis results for predictors of current rating (listwise N = 328)*

Variable	Serious Chess Activity	Chess Instruction
Total study time	.97	-.09
Total tournament play	.61	.06
Books	.43	.23
Total private instruction	.10	.43
Total group instruction	-.03	.69
Eigenvalues	2.25	1.03
% of variance	45.03	20.65

Note: Factor loadings $\geq .40$ appear in bold.

The second step in the SEM was to assess the effect of Serious Chess Activity and Chess Instruction, along with serious starting age, on peak rating and current rating. Results for peak rating and current rating are illustrated in Figure S2 (henceforth, as in the figure, values are presented for both peak rating and current rating, as peak/current). Serious Chess Activity had a significant positive effect on rating (.66/.57, $ps < .001$), whereas the effect of Chess Instruction was near zero (.15/.15, $ps > .05$). Furthermore, serious starting age had a significant negative effect on rating (-.14/-.20, $ps < .05$), above

and beyond the chess experience factors. Collectively, the model accounted for 62.4% of the variance in peak rating and 53.0% of the variance in current rating. Model fit was acceptable for both peak rating, $\chi^2(10) = 39.81, p < .001, CFI = .95, NFI = .93, RMSEA = .10$, and for current rating, $\chi^2(10) = 49.27, p < .001, CFI = .93, NFI = .91, RMSEA = .11$.

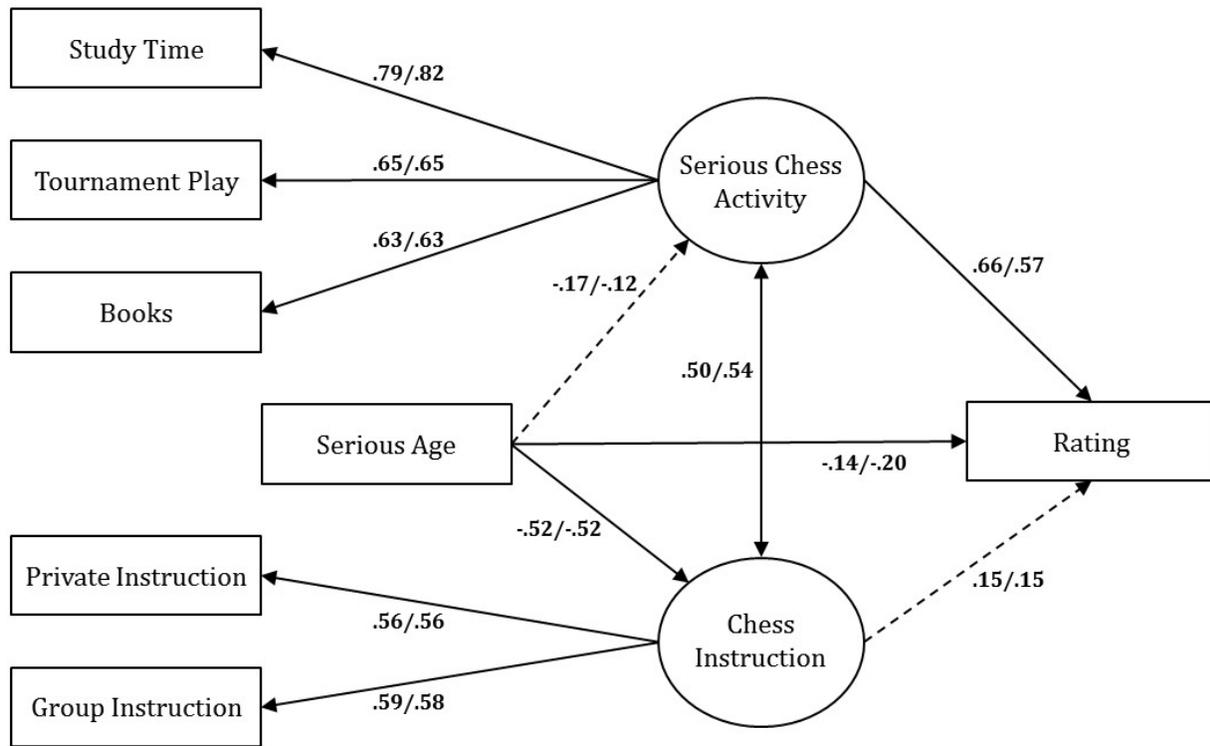


Figure S2. Structural equation model predicting peak rating (listwise $n = 328$) and current rating (listwise $n = 328$). The path from Serious Age to Serious Chess Activity was significant for peak rating but nonsignificant for current rating. The path from Chess Instruction to rating was nonsignificant for peak rating and current rating.

Additional Analyses for Peak Rating

Competition experience. We used hierarchical multiple regression to examine whether competition experience (i.e., peak tournament play) contributed to the prediction of peak rating above and beyond the expected contribution of serious study and formal

instruction. We entered peak study time, peak private instruction, and peak group instruction in Step 1 of the model and peak tournament play in Step 2 of the model.

The overall model accounted for 40.4% of the variance in peak rating, $F(4, 323) = 54.74$, $SEE = 202$, $p < .001$ (Table S8). Tournament play significantly contributed to the prediction of peak rating above and beyond study time and formal instruction, $\Delta R^2 = .01$, $p < .05$.

Table S8. *Hierarchical regression of peak rating on deliberate practice and other predictor variables for tournament-rated chess players (N = 328)*

	ΔR^2	Sig. F Change	B	β	t
Step 1	.39	< .001			
Peak study time			214.0	.43	7.96***
Peak private instruction			140.8	.18	3.87***
Peak group instruction			90.4	.14	2.95**
Step 2	.01	< .05			
Peak tournament play			73.2	.13	2.44*

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Serious study and formal instruction. We used multiple regression to test the hypothesis that the effect of serious study on peak rating was moderated by formal instruction such as private lessons and group lessons. We also tested whether serious study was moderated by chess books, another training aid. We took standardized scores for peak study time, peak private instruction, peak group instruction, and books, and computed Peak Study Time \times Peak Private Instruction, Peak Study Time \times Peak Group Instruction, and Peak Study Time \times Books interaction terms (Aiken, West & Reno, 1991). Next, we entered peak study time, peak tournament play, peak private instruction, peak group instruction, books, and serious starting age in Step 1 of the model, and the preceding interaction terms in Step 2.

The overall model accounted for 52.7% of the variance in peak rating, $F(9, 318) = 39.31$, $SEE = 181$, $p < .001$ (Table S9). The interaction terms did not contribute significantly to the prediction of peak rating, $\Delta R^2 = .005$, $p = .36$.

Table S9. Hierarchical regression of peak rating on predictor variables for tournament-rated chess players ($N = 328$)

	ΔR^2	Sig. F Change	B	β	t
Step 1	.52	< .001			
Peak study time			145.8	.29	5.67***
Peak tournament play			55.1	.10	2.03*
Peak private instruction			113.1	.14	2.96**
Peak group instruction			20.7	.03	0.71
Books			169.3	.34	7.52***
Serious age			-6.2	-.19	-4.45***
Step 2	.005	.36			
Study \times Private Instruction			-8.7	-.04	-0.73
Study \times Group Instruction			7.7	.03	0.69
Study \times Books			-15.3	-.06	-1.41

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Age subsets. We conducted multiple regression analyses on predictors of peak rating for older (age ≥ 44) and younger (age < 44) chess players (Table S10). For older chess players, the model accounted for 54.0% of the variance in peak rating, $F(6, 95) = 18.59$, $SEE = 178$, $p < .001$. For younger chess players, the model accounted for 54.3% of the variance in peak rating, $F(6, 219) = 43.41$, $SEE = 180$, $p < .001$. For younger chess players, study time, tournament play, private instruction, books, and serious age were significant predictors of peak rating. For older chess players, only study time and books were significant predictors of peak rating.

Table S10. Hierarchical regression of peak rating on predictor variables for younger (age < 44) and older (age ≥ 44) tournament-rated chess players.

	Younger (n = 226)				Older (n = 102)			
	<i>R</i> ²	<i>B</i>	β	<i>t</i>	<i>R</i> ²	<i>B</i>	β	<i>t</i>
Step 1	.54				.54			
Peak study time		175.7	.35	5.81***		140.5	.26	2.84**
Peak tournament play		78.1	.13	2.32*		65.6	.12	1.31
Peak private instruction		107.1	.13	2.66**		43.5	.06	0.72
Peak group instruction		18.0	.03	0.47		12.2	.02	0.26
Books		139.9	.27	4.92***		219.1	.47	5.86***
Serious age		-7.7	-.14	-2.52*		-2.8	-.12	-1.60

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; *B*, unstandardized regression coefficient; β , standardized regression coefficient.

Additional Analyses for Current Rating

Competition experience. We used hierarchical multiple regression to examine whether competition experience (i.e., total tournament play) contributed to the prediction of current rating above and beyond the expected contribution of serious study and formal instruction. We entered total study time, total private instruction, and total group instruction in Step 1 of the model and total tournament play in Step 2 of the model.

The overall model accounted for 34.8% of the variance in current rating, $F(4, 323) = 43.18$, $SEE = 219$, $p < .001$ (Table S11). Tournament play did not significantly contribute to the prediction of current rating above and beyond study time and formal instruction, $\Delta R^2 = .00$, $p > .05$.

Table S11. *Hierarchical regression of current rating on deliberate practice and other predictor variables for tournament-rated chess players (N = 328)*

	ΔR^2	Sig. F Change	<i>B</i>	β	<i>t</i>
Step 1	.35	< .001			
Total study time			226.4	.43	7.58***
Total private instruction			171.1	.21	4.39***
Total group instruction			72.7	.11	2.19*
Step 2	.00	> .05			
Total tournament play			26.6	.05	0.83

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; *B*, unstandardized regression coefficient; β , standardized regression coefficient.

Serious study and formal instruction. Next, we used multiple regression to test the hypothesis that the effect of serious study on current rating was moderated by training aids such as private lessons, group lessons, or chess books. We took standardized scores for total study time, total private instruction, total group instruction, and books, and computed Total Study Time \times Total Private Instruction, Total Study Time \times Total Group Instruction, and Total Study Time \times Books interaction terms. Next, we entered total study time, total tournament play, total private instruction, total group instruction, books, and serious starting age in Step 1 of the model, and the preceding interaction terms in Step 2.

The overall model accounted for 48.8% of the variance in current rating, $F(9, 318) = 33.62$, $SEE = 195$, $p < .001$ (Table S12). The interaction terms did not contribute significantly to the prediction of current rating, $\Delta R^2 = .008$, $p = .16$.

Table S12. Hierarchical regression of current rating on predictor variables for tournament-rated chess players ($N = 328$)

	ΔR^2	Sig. F Change	B	β	t
Step 1	.48	< .001			
Total study time			155.3	.29	5.45***
Total tournament play			14.3	.03	0.50
Total private instruction			155.1	.19	3.82***
Total group instruction			-2.9	.00	-0.09
Books			169.9	.33	6.84***
Serious age			-7.7	-.23	-5.09***
Step 2	.008	.16			
Study \times Private Instruction			-18.3	-.08	-1.47
Study \times Group Instruction			0.6	.00	0.45
Study \times Books			-13.1	-.05	-1.22

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Age subsets. We conducted multiple regression analyses on predictors of current rating for older (age ≥ 44) and younger (age < 44) chess players (Table S13). For older chess players, the model accounted for 54.3% of the variance in current rating, $F(6, 95) = 18.84$, $SEE = 186$, $p < .001$. For younger chess players, the model accounted for 51.0% of the variance in current rating, $F(6, 219) = 38.05$, $SEE = 190$, $p < .001$. For younger chess players, study time, private instruction, books, and serious age were significant predictors of current rating. For older chess players, only study time and books were significant predictors of current rating.

Table S13. Hierarchical regression of current rating on predictor variables for younger (age < 44) and older (age ≥ 44) tournament-rated chess players.

	Younger (n = 226)				Older (n = 102)			
	R^2	B	β	t	R^2	B	β	t
Step 1	.51				.54			
Peak study time		182.2	.34	5.59***		205.8	.35	3.78***
Peak tournament play		38.8	.06	1.10		91.7	.14	1.67
Peak private instruction		114.2	.14	2.72**		73.0	.09	1.17
Peak group instruction		0.0	.00	0.00		-44.5	-.07	-0.89
Books		161.1	.30	5.46***		184.7	.37	4.54***
Serious age		-9.6	-.17	-2.96**		-2.6	-.11	-1.45

Note. * $p < .05$; ** $p < .01$; *** $p < .001$; B , unstandardized regression coefficient; β , standardized regression coefficient.

Graphs Depicting Distribution of Peak Chess Variables Used in Main Analyses

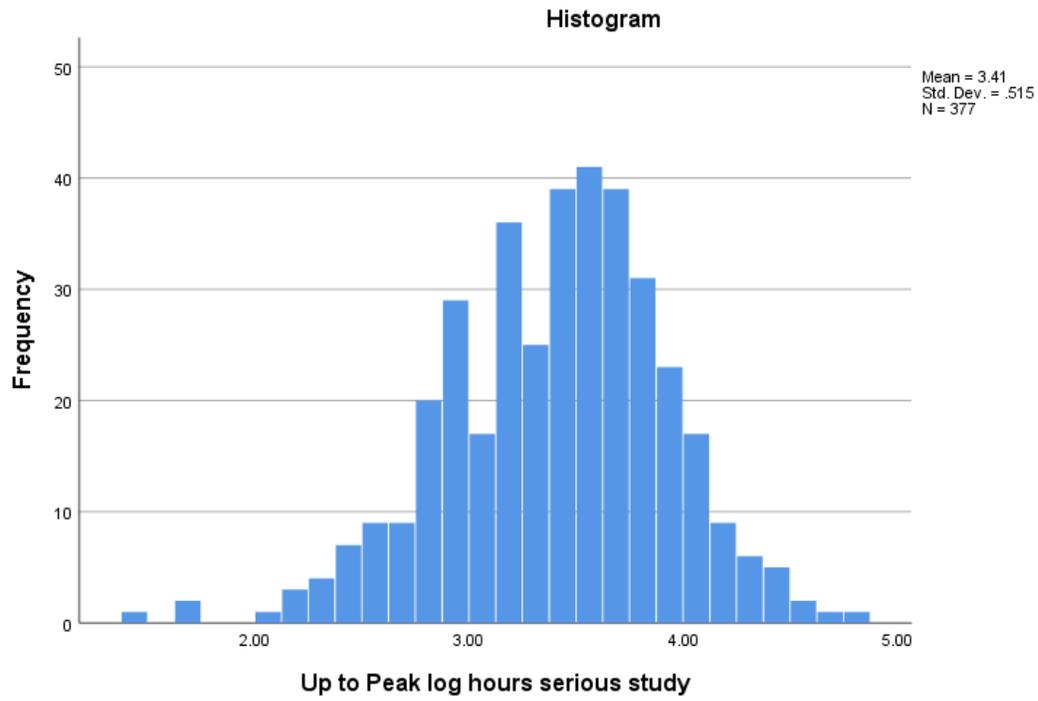


Figure S3. Histogram of peak log hours serious study.

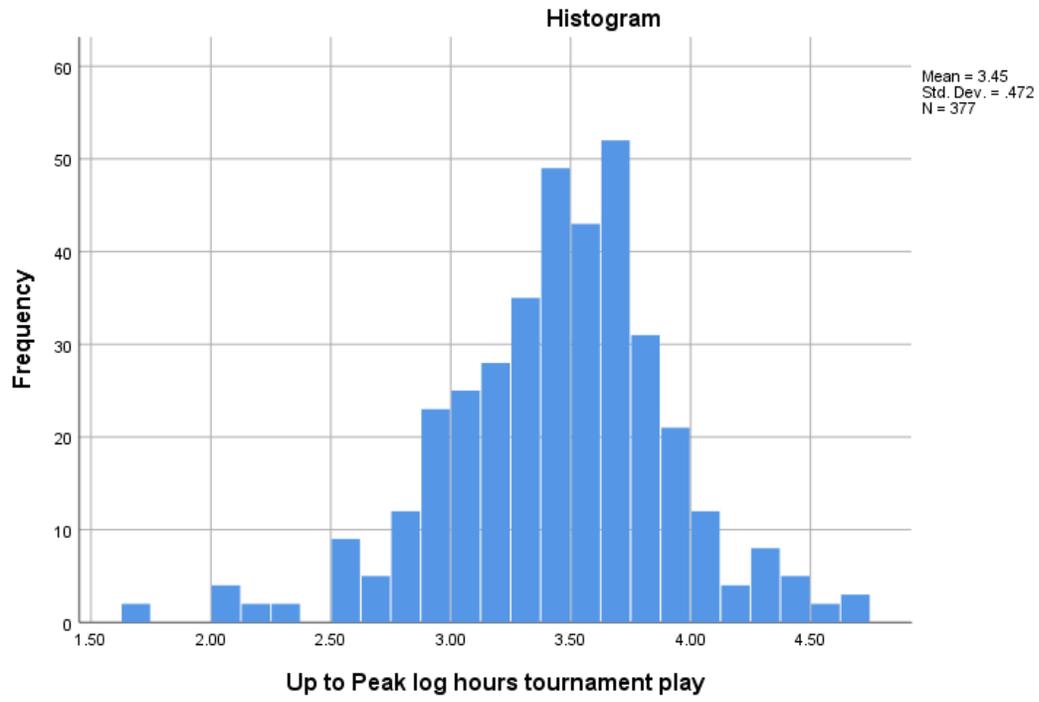


Figure S4. Histogram of peak log hours tournament play.

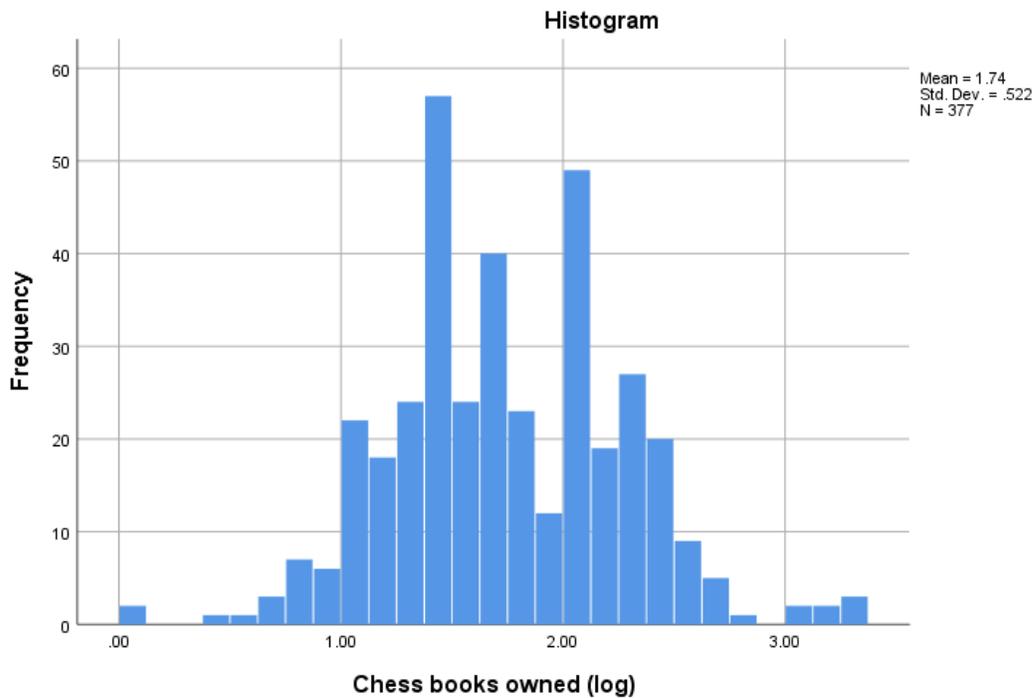


Figure S5. Histogram of log chess books owned.

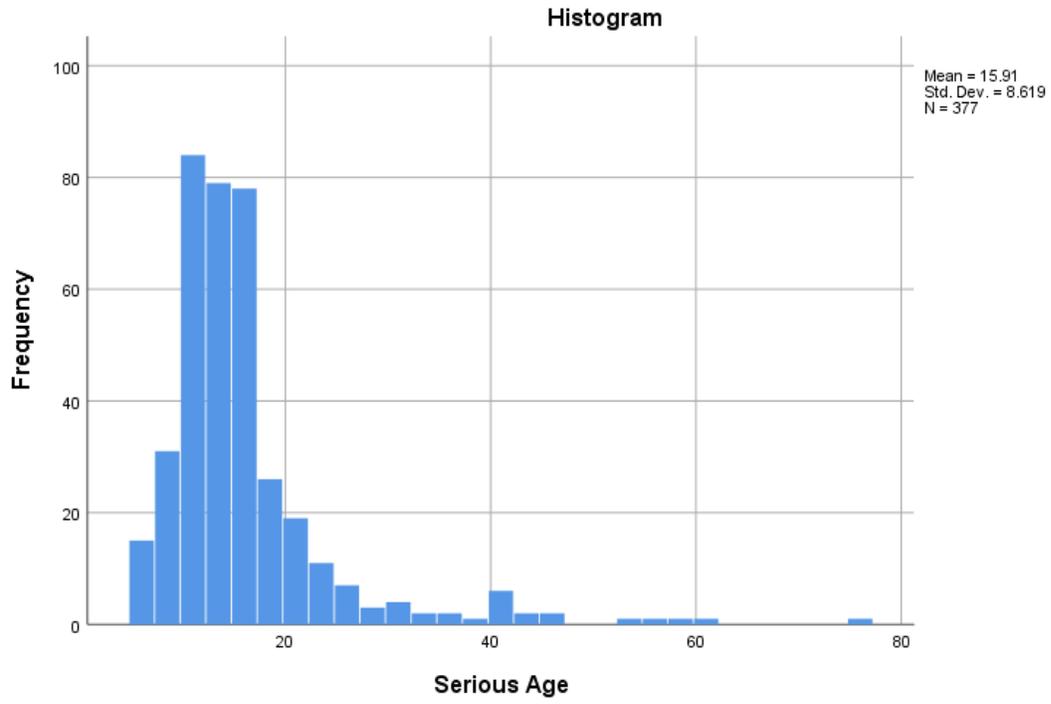


Figure S6. Histogram of serious starting age.

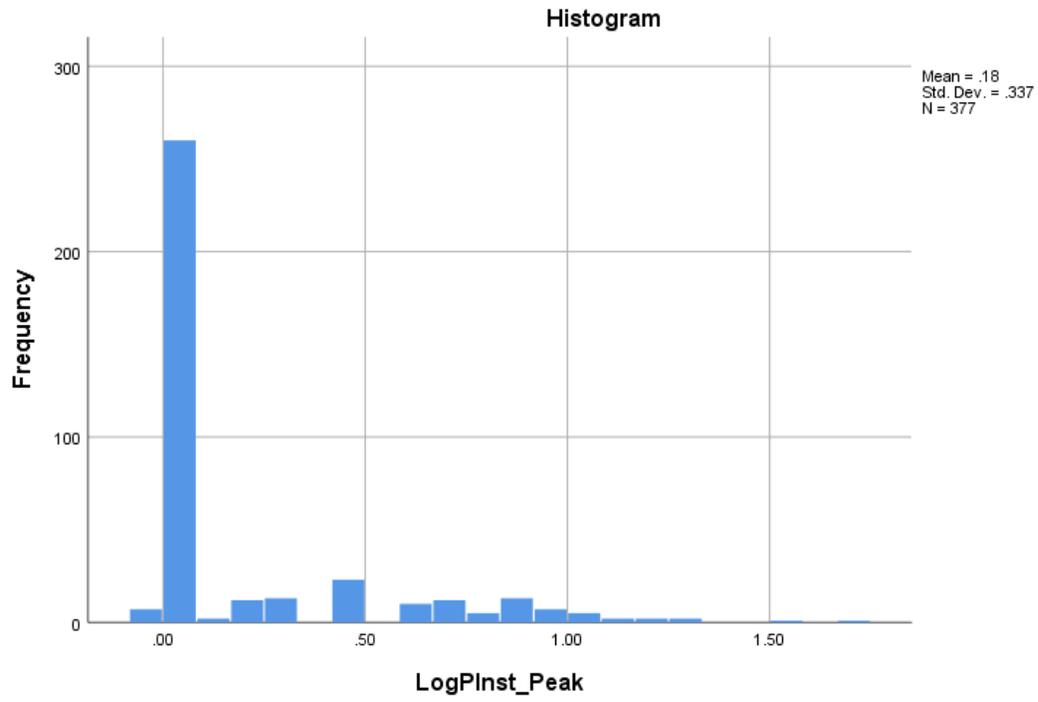


Figure S7. Histogram of log years private instruction until peak age.

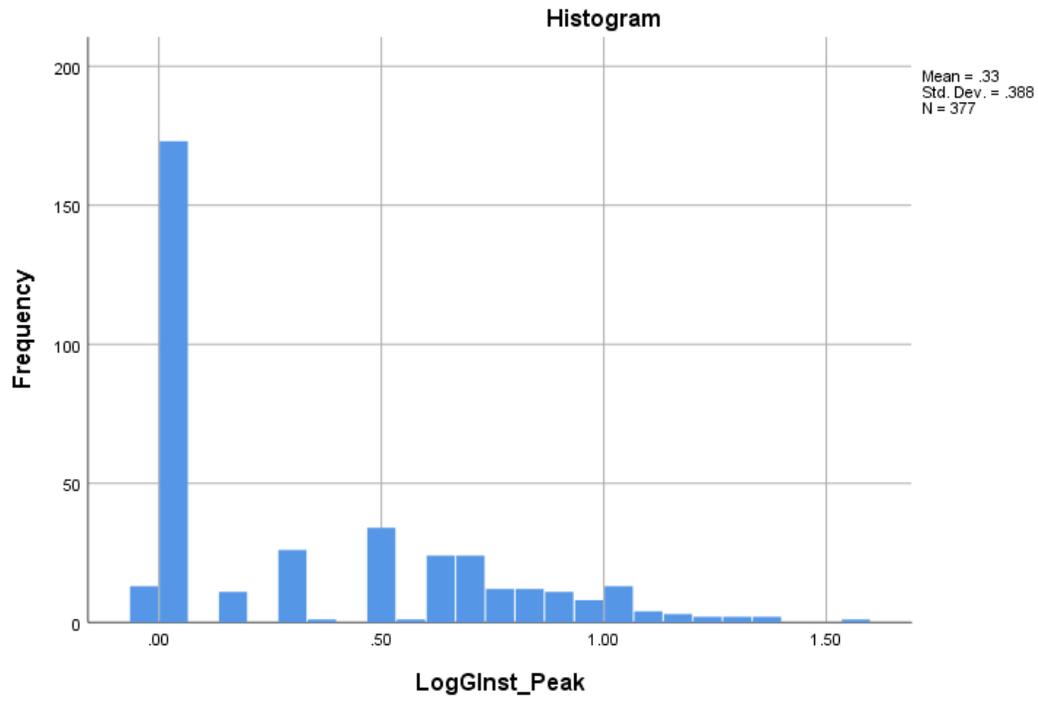


Figure S8. Histogram of log years group instruction until peak age.