Supplementary Appendix 1

Detailed description of the screening procedure

On December 2015 the first author (FA) and second author (SA) performed a systematic literature search by using three popular databases in psychology and related disciplines: Web of Science (WoS), PsycINFO (PI), and PubMed (PM). We limited our search to the previous five full years, that is, from January 1st, 2010, to December 31st, 2014. We based the search on two groups of terms, one for the statistical model and the other for the substantive field of application. All (statistical and substantive) terms were searched anywhere in the text (e.g., title, abstract, body text). We required that the records returned from the search be journal articles, book chapters, or books, written in English. The aim of the literature search was to evaluate current practice of substantive researchers in non-pathological cognitive aging, who analyzed longitudinal data with some form of growth model. Thus, we excluded hits that were statistical/methodological in nature (that were tutorials, or that focused on studying properties of such models).

Terms concerning the statistical model were: "growth curve model*"; "latent curve model*"; "multilevel model*"; "mixed effects model*"; "linear mixed model*"; "random effects model*"; "hierarchical linear model*"; "nonlinear hierarchical model*"; "generalized linear mixed model*"; "nonlinear mixed model*". We included the wildcard "*" to include variations (such as modeling, modelling, models, etc.). Growth curve and latent curve models are by definition applied to longitudinal data, whereas those within the multilevel family can also be applied to cross-sectional data (e.g., typically hierarchically organized data, such as children within schools) or to meta-analyses (to account for both across-studies and within-study variations). Thus, for this latter class of models we added the "longitudinal" term. The terms concerning the statistical model were combined with two terms concerning the substantive application: "intelligence" and "cogniti*". We again included the wild card "*" to assure coverage of related terms such as cognition, cognitive, cognitively, etc. We refrained from searching for specific cognitive abilities (e.g., speed, episodic or working memory, inhibition), because of the very large number of terms that such a search would have required. Moreover, we reasoned that scientific writings focused on specific abilities are very likely to include the terms "intelligence" and/or "cogniti*" in their text.

The supplemental Table 1 shows the number of records from each literature database for each combined use of statistical and substantive search terms. The last column shows the sum across the three databases. The row named Sum shows the total number of records across all search terms from each database: 593 for WoS, 571 for PI, and 89 for PM, for a total of 1253 records. First, the FA and SA independently eliminated first all duplicate records within each database and for this first step obtained full agreement. The resulting numbers of retained records were 536 for WoS, 493 for PI, and 82 for PM, for a total of 1111 records. Then, FA and SA independently eliminated duplicate and non-English records across databases, and obtained a final number of 719 entries, again with full agreement. Duplicates were established based on authors' names, title and date of record, and name of publication.

Second, FA and SA independently read the abstracts of 182 records (a fourth) to screen them for eligibility, according to the criteria listed below. That is, despite the inclusion of the search terms, a record could be unrelated to the aims of the search (in few cases the abstract was not sufficient and portions of the text had to be read). At this stage, the FA and SA had a 0.73

agreement index. Thus, the FA and SA together analyzed, discussed, and reclassified the discordant records to reach full consensus.

Third, the FA and SA independently read and classified the abstracts of the remaining (719 – 182 =) 537 records. At this stage, the FA and SA had a 0.88 agreement index. They again reclassified the discordant records to reach full consensus. In the end, of the 719 records, the following were excluded:

- n=4, because they were commentary articles (n=2), reviews (n=1), or corrections (n=1);
- n=1, because it was a conference poster and only the abstract was available;
- n=20, because they were meta-analyses;
- n=7, because they did not include longitudinal/repeated measurement data (e.g., mixed-effects models were used on cross-sectional data with heterogeneous variances across conditions, or with siblings or neighborhoods as clusters);
- n=48, because they were of statistical or methodological nature [1];

[1] i.e., that appeared in specialized journals (The American Statistician; Annals of Applied Statistics; Applied Psychological Measurement; Behavior research methods; Biometrical Journal; Biometrical Journal; Biometrika; British Journal of Mathematical and Statistical Psychology; Computational Statistics and Data Analysis; Frontiers in Psychology: Quantitative Psychology and Measurement; Journal of the American Statistical Association; Journal of Applied Statistics; Journal of Biometrics and Biostatistics; Journal of Computational and Graphical Statistics; Journal of Educational and Behavioral Statistics; Journal of the Royal Statistical Society, Series A, Statistics in Society; Journal of the Royal Statistical Society, Series C, Applied Statistics; Methodology; Multivariate Behavioral Research; Psychological Methods; Psychometrika; Statistical Methods in Medical Research; Statistical Modelling; Statistics in Medicine; Structural Equation Modeling; Statistical Methodology), that appeared in substantive journals but that focused on methodological/statistical issues (American Journal of Epidemiology; The American Journal of Geriatric Psychiatry; Annals of Epidemiology; Contemporary Clinical Trials; European Journal of Developmental Psychology; Journal of Cognition and Development; Neuroepidemiology; NeuroImage; Psychology and Aging; Sleep Medicine; World Journal of Biological Psychiatry), or that appeared in methodological or statistical books (e.g., Contemporary issues in exploratory data mining in the behavioral sciences; Handbook for advanced multilevel analysis; The handbook of life-span development; Handbook of structural equation modeling; Longitudinal data analysis: A practical guide for researchers in aging, health, and social sciences; Quantitative and qualitative methods in psychotherapy research).

- n=128, because they included and focused on non-normal samples (e.g., patients with Alzheimer, Parkinson, autism, depression, bipolar disorders, breast cancer, MCI, heavy drinkers);
- n=243 did not include samples of elderly individuals (age $<$ 65 years);
- n=349 did not specify cognitive or intelligence performance as dependent variable of analysis (e.g., controlled for cognitive variables but specified non-cognitive dependent variables, or discussed relevance of findings in terms of general cognitive functioning, without explicit assessment or analysis of cognitive variables).

Many records met multiple exclusion criteria (e.g., n=149 did not include samples of elderly individuals and did not specify cognitive or intelligence performance as dependent variable of analysis; n=70 included non-normal samples and did not specify cognitive or intelligence performance as dependent variable of analysis). In the end, we retained and fully analyzed n=162 records. The screening procedure is represented in the Supplemental Figure 1.

Supplementary Appendix 2

Records in final analysis based on the literature review

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Supplementary Appendix 3

Detailed results of literature review

The literature search produced 1253 records, and after exclusion of duplicate and irrelevant records, we fully analyzed 162 records. See Supplementary Appendix 1 and Supplementary Figure 1 for full details.

Of the 162 records, the data were of panel type for 156 records, and experimental for six.

The number of repeated measurements ranged from 2 to 20, with a mean of 5.071 (median = 5, s.d. = 2.895, interquartile range = 3 to 6; information not available for nine records).

Multilevel/mixed effects type models were used in 135 records (one with a penalized linear spline; one with a thin plate regression spline; one was nonlinear in the parameters; one was a generalized mixed-effects model), whereas a latent curve type model was used in 26 records (three analyzed multiple variables in parallel; one was a 2^{nd} level curve model; two used a structured latent curve model). Finally, the remaining record applied both models.

One hundred and two records (63%) tested only a linear change function, and of these only one had experimental data, whereas the remaining 101 were panel studies. Moreover, the number of occasions ranged from 2 to 17 (median = 4.000, mean = 4.792, s.d. = 2.927). Forty (25%) studies tested also a quadratic function, and of these all were panel studies, with between 2 and 12 occasions (median = 5.000, mean = 5.351, s.d. = 2.163). One study tested a cubic function, and this study was a panel with five occasions.

Thirteen (8%) records tested a broken-stick function (a.k.a. single-node spline; ten of which compared it to a linear or quadratic function). These were all panel studies, with between 3 and 6 occasions (median = mean = 5.000, s.d. = 1.265).

Of the remaining records, five (3%) tested an exponential function (all with experimental data, with from 5 to 20 occasions, median=8.000, mean = 9.800, s.d. = 6.017), two (1%) estimated the change function from the data (within a latent curve model; both were panel studies, with either 3 or 4 occasions), one used a multiple-node spline approach (a panel study with 7 occasions), and one did not specify the change function (a panel study with 6 occasions). Overall, of the eight records that tested a nonlinear function, five were on experimental data, with number of occasions ranging from 5 to 20 (median = 8.000, mean = 9.800, s.d. = 6.017); all used occasions of measurement as the time basis; all applied an exponential function, and one also estimated the change function within a latent curve model.

Across all studies, the most frequent time bases were time in study (n = 76), occasions of measurement (n = 41), chronological age (n = 33), and time to event (n = 13; e.g., death, dementia, stroke, hospitalization). One record used a time-varying medical covariate as basis, and three records did not provide this information. Finally, five records used and compared two of the aforementioned bases.

Supplementary Appendix 4

Logistic regression to study the determinants of an acceptable solution

To understand which design feature most strongly influences the probability of obtaining an acceptable solution, we computed a logistic regression analysis. The dichotomous variable was AS vs. non-AS, and the predictors were model type, GCR, T, Δ, and N. We computed this analysis for the shallower exponential decline rate only ($\gamma = 0.033$), given the very high number of AS for $\gamma = 0.066$. For simplicity, we present the analyses including all main effects only (all interactions proved irrelevant). Below we display the type-III likelihood ratio tests concerning each simulation factor, with its degrees of freedom and *p*-value, and the drop in effect size measures when each simulation factor is omitted from the logistic equation. The strongest effect was by far associated to the model type, while all other factors were associated to much weaker effect sizes.

Factor (df)	LRT	$\sim R^2 CS$	$\sim R^2 N$
model (3)	5490.772	.126	.249
GCR (2)	1921.237	.042	.083
T (1)	1845.481	.040	.079
Δ (4)	1239.208	.027	.053
N (2)	225.037	.005	.009
$\sim R^2 CS$	.232 (.269)		
$\sim R^2 N$	.457 (.529)		

Note. LRT=Type-III likelihood ratio tests associated to each simulation factor and design feature (rows) in a logistic regression predicting the probability of obtaining an acceptable solution (the associated degrees of freedom are in parenthesis; all *p*-values are <.001). $\sim R^2CS$ and $\sim R^2N$ = drop in pseudo R^2 of Cox and Snell and pseudo R^2 of Nagelkerke, respectively, when that effect is removed from the regression equation. The lower panel presents the total effect size indexes of pseudo R^2 of Cox and Snell (tot. R^2 CS) and of Nagelkerke (tot. R^2 N) with only the main effects, and in parentheses the analogous estimates with the addition of all interactions.

Supplementary Appendix 5

Summary of results of analyses on rejections of the linear GM and the quadratic GM when compared to the exponential GM and of the linear GM when compared to the quadratic GM for $\gamma = 0.033$ only (based on difference in BIC greater than 10)

	Linear vs. Exponential			Quadratic vs. Exponential			Linear vs. Quadratic		
Factor (df)	LRT	R^2CS	R^2N	LRT	R^2CS	R^2N	LRT	R^2CS	R^2N
GCR (2)	1575.403	.112	.159	830.301	.084	.113	991.222	.196	.307
T (1)	2443.488	.185	.261	1324.233	.140	.187	2096.576	.251	.382
Δ (4)	2503.807	.190	.269	1236.640	.130	.173	2171.507	.208	.296
N (2)	1200.185	.083	.118	288.879	.028	.037	870.941	.139	.232
tot. R^2 CS	.511 (.539)			.403 (.547)			.514 (.538)		
tot. R^2 N	.723 (.763)			.538 (.730)			.733 (.766)		

Note. LRT=Type-III likelihood ratio tests associated to each simulation factor and design feature (rows) for the linear vs. exponential (columns 2-4), quadratic vs. exponential (columns 5-7), and linear vs. quadratic (columns 8-10) GMs in logistic regressions predicting the probability of rejecting the linear or quadratic GM when compared to the exponential GM or the linear GM when compared to the quadratic GM (the associated degrees of freedom are next to the name of each term; all *p*-values are < .001). R^2CS and R^2N = drop in pseudo R^2 of Cox and Snell and pseudo R^2 of Nagelkerke, respectively, when that effect is removed from the regression equation. The lower panel presents the total effect size indexes of pseudo R^2 of Cox and Snell (tot. R^2 CS) and of Nagelkerke (tot. R^2 N) with only the main effects, and in parentheses the analogous estimates with the addition of all interactions.

Supplementary Appendix 6

Summary of Results of Analyses on Power to Detect Change Variance for $\gamma = 0.033$

Because the true variance in change (σ^2_C) is at a boundary (i.e., cannot be negative), we used a 50:50 mixture of a 1- and 2-degree-of-freedom chi square distribution (Self & Liang, 1987; Stoel, Garre, Dolan, & van den Wittenboer, 2006) to compute all likelihood ratio tests. However, given the reservations raised by some about this methodology (e.g., Savalei & Kolenikov, 2008), we also applied a 2-degree-of-freedom test. The results were identical.

	Linear			Quadratic			Exponential		
Factor (df)	LRT	R^2CS	R^2N	LRT	R^2CS	R^2N	LRT	R^2CS	R^2N
GCR (2)	248.320	.024	.043	493.457	.058	.096	546.575	.047	.077
T (1)	702.835	.071	.125	725.443	.087	.143	741.567	.065	.106
Δ (4)	932.453	.096	.168	993.848	.122	.200	1192.894	.107	.176
N (2)	660.821	.067	.117	279.642	.032	.053	901.961	.079	.131
total ~R^2 CS	.241 (.272)			.272 (.318)			.282 (.317)		
total ~R^2 N	.422 (.477)			.448 (.524)			.464 (.522)		

Note. Type-III likelihood ratio tests associated to each simulation factor and design feature (rows) for the linear (columns 2-4), quadratic (column 5-7), and exponential (column 8-10) GMs in logistic regressions predicting the probability of rejecting the alternative models in which $\sigma^2_C = \sigma_{LC} = 0$ (the associated degrees of freedom are next to the name of each term; all *p*-values are <.001). R^2CS and R^2N = drop in pseudo R^2 of Cox and Snell and pseudo R^2 of Nagelkerke, respectively, when that effect is removed from the regression equation. The lower panel presents the total effect size indexes of pseudo R^2 of Cox and Snell (total ~R^2 CS) and of Nagelkerke (total ~R^2 N) with only the main effects, and in parentheses the analogous estimates with the addition of all interactions.

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Supplementary Table 1

Number of records from each literature database for each combined use of statistical and substantive search terms

Search terms		Database			
Statistical	**Substantive**	**WoS**	**PI**	**PM**	**all**
"Growth curve model*"	"cogniti*"	164	128	16	308
"Growth curve model*"	"intelligence"	22	34	4	60
"Latent curve model*"	"cogniti*"	7	5	0	12
"Latent curve model*"	"intelligence"	2	2	0	4
"multilevel model*" and "longitudinal"	"cogniti*"	74	74	1	149
"multilevel model*" and "longitudinal"	"intelligence"	12	30	1	43
"mixed effects model*" and "longitudinal"	"cogniti*"	104	84	26	214
"mixed effects model*" and "longitudinal"	"intelligence"	7	16	2	25
"linear mixed model*" and "longitudinal"	"cogniti*"	98	79	23	200
"linear mixed model*" and "longitudinal"	"intelligence"	6	17	2	25
"random effects model*" and "longitudinal"	"cogniti*"	40	19	9	68
"random effects model*" and "longitudinal"	"intelligence"	0	2	0	2
"hierarchical linear model*" and "longitudinal"	"cogniti*"	48	52	4	104
"hierarchical linear model*" and "longitudinal"	"intelligence"	3	13	0	16
"nonlinear hierarchical model*" and "longitudinal"	"cogniti*"	0	0	0	0
"nonlinear hierarchical model*" and "longitudinal"	"intelligence"	0	0	0	0
"generalized linear mixed model*" and "longitudinal"	"cogniti*"	5	13	1	19

“generalized linear mixed model*” and “longitudinal”	“intelligence”	0	3	0	3
“nonlinear mixed model*” and “longitudinal”	“cogniti*”	1	0	0	1
“nonlinear mixed model*” and “longitudinal”	“intelligence”	0	0	0	0
Sum		593	571	89	1253
Records without intra-base duplicates		536	493	82	1111
Records without inter-bases duplicates			719		
Records retained for full lecture			**162**		

Notes. WoS=Web of Science; PI=PsycINFO; PM=PubMed.

Supplementary Table 2
Parameter Estimates (and Standard Errors) of the Linear, Quadratic, and Exponential GM applied to the Recall Score in the Betula Study.

parameter	level GM	linear GM	quadratic GM	exponential GM
β_0	23.521 (0.251)	23.506 (0.214)	24.615 (0.218)	20.603 (0.439)
β_1	--	-0.254 (0.012)	-0.341 (0.013)	-4.007 (0.451)
β_2	--	--	-0.009 (<0.001)	--
γ	--	--	--	0.066 (0.004)
σ^2_L	55.518 (2.840)	33.758 (2.246)	30.779 (1.983)	30.980 (2.786)
σ^2_C	--	0.032 (0.007)	0.027 (0.006)	5.041 (1.402)
$\sigma_{L,C}$ [$\rho_{L,C}$]	--	0.638 (0.086) [0.619]	0.379 (0.072) [0.413]	-3.163 (1.599) [-0.253]
σ^2_E	18.148 (0.576)	16.444 (0.597)	14.942 (0.541)	14.541 (0.526)
-2LL	19‘453	18’911	18’692	18’686
BIC	19‘473	18’952	18’741	18’734
p	3	6	7	7

Note. GM=growth model. $\rho_{L,C}$ = correlation between level and change. p = number of estimated parameters. All models were estimated with age centered at 65 years. Standard errors are in parentheses. For the quadratic model and the exponential model it was not possible to estimate the variance, respectively, of the quadratic slope and of the exponential decline rate.

Supplementary Table 3

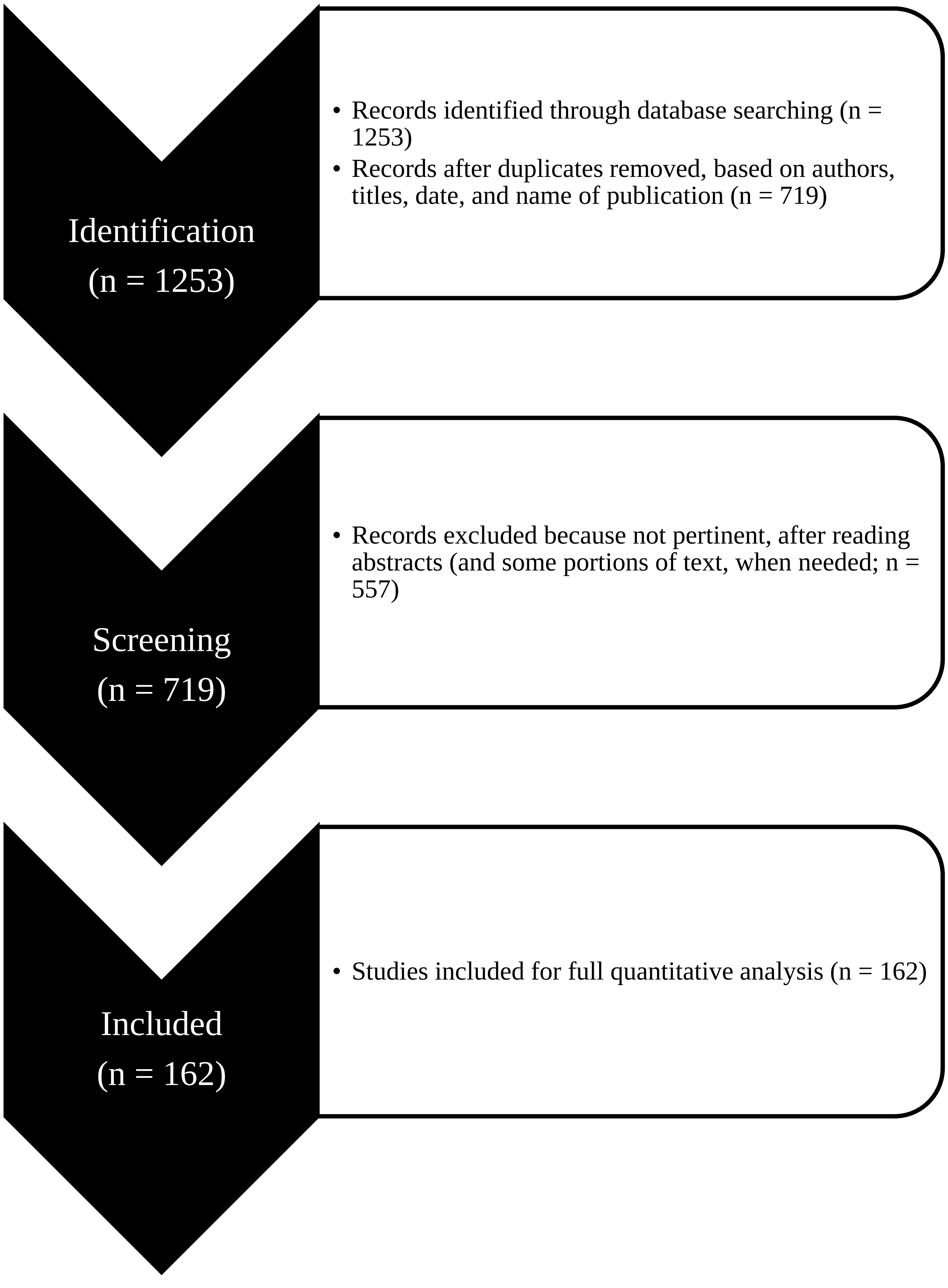
Factors in Simulation Study

Constant Simulation Factors	
Level mean (β_0)	20.603
Change mean (β_1)	-4.007
Level variance (σ^2_L)	30.980
Change variance (σ^2_C)	5.041
Level-change covariance ($\sigma_{L,C}$)	-3.163
Varying Simulation Factors	
Rate of exponential decline (γ)	0.033, 0.066
Growth Curve Reliability $\left(GCR = \frac{\sigma_L^2}{\sigma_L^2 + \sigma_E^2}\right)$	.500, .681, .900
Varying Design Factors	
Occasions (T)	3, 6
Interval (Δ)	1, 2, 3, 4, 5
Total sample size (N)	500, 1000, 2000

Note. The factors refer to the exponential decline function (Equation (4)). The full design includes 5 fully crossed varying factors (γ, GCR, T, Δ, N) for a total of 2 x 3 x 2 x 5 x 3) = 180 conditions. On each condition 4 growth models were tested (level, linear, quadratic and exponential) and each condition contained 100 replications. In the end, we obtained 180 x 4 x 100 = 72000 sets of solutions.

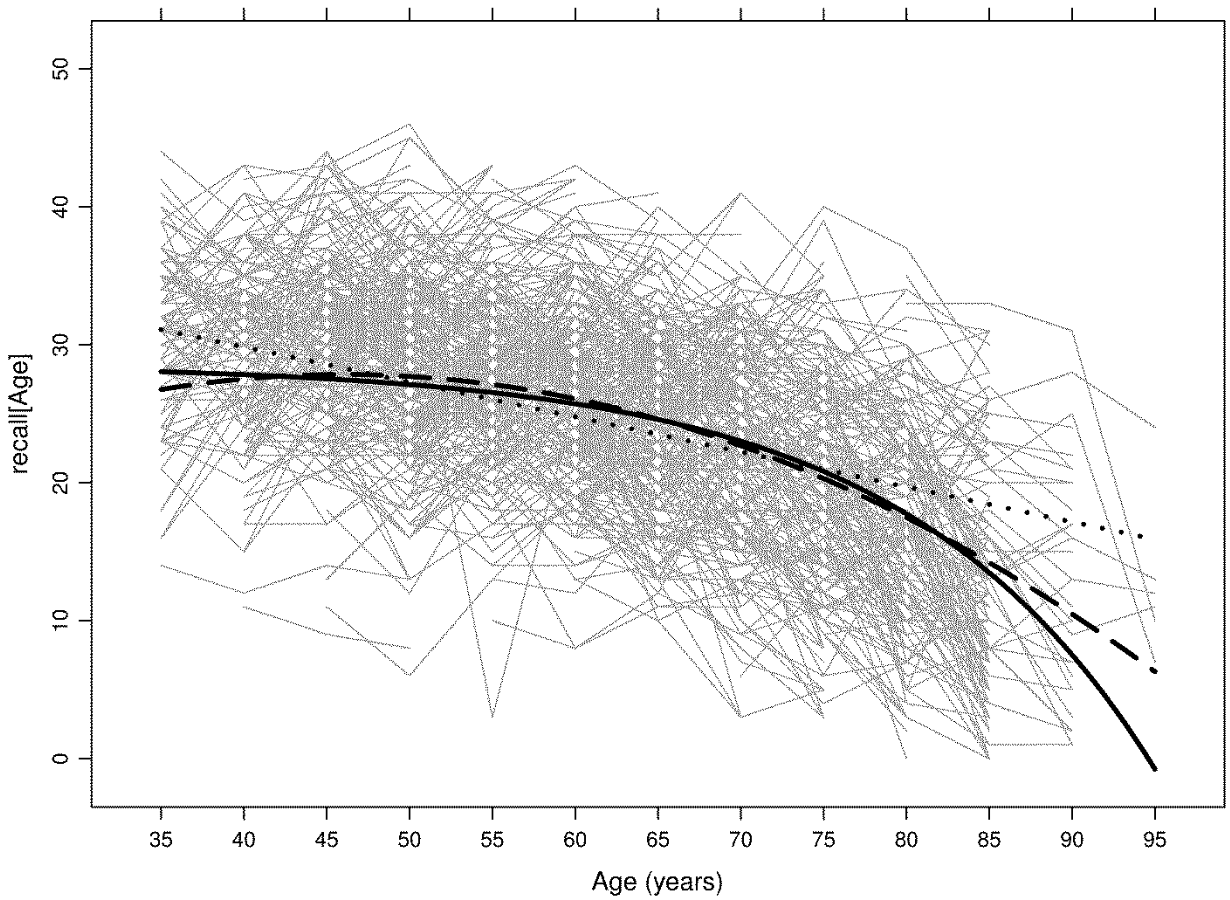
Supplementary Figure 1

Flowchart with screening procedure of articles included in the quantitative analysis



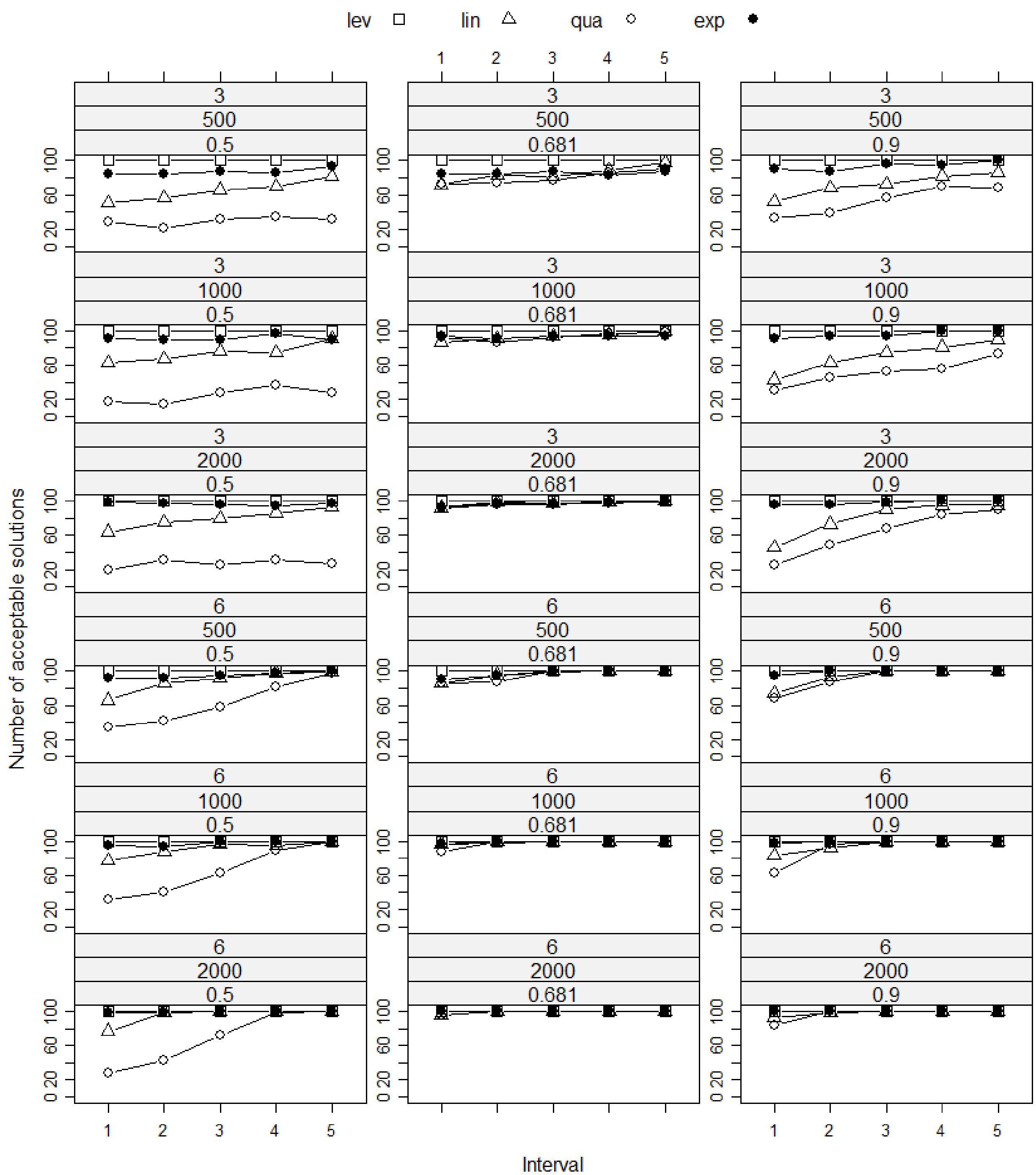
Supplementary Figure 2

Betula recall scores by age



Note. The sample predicted trajectory is represented by the black dotted line for the linear GM, the black dashed line for the quadratic GM, and the continuous black line for the exponential decline GM. The grey lines represent the observed individual trajectories (*N* = 1000).

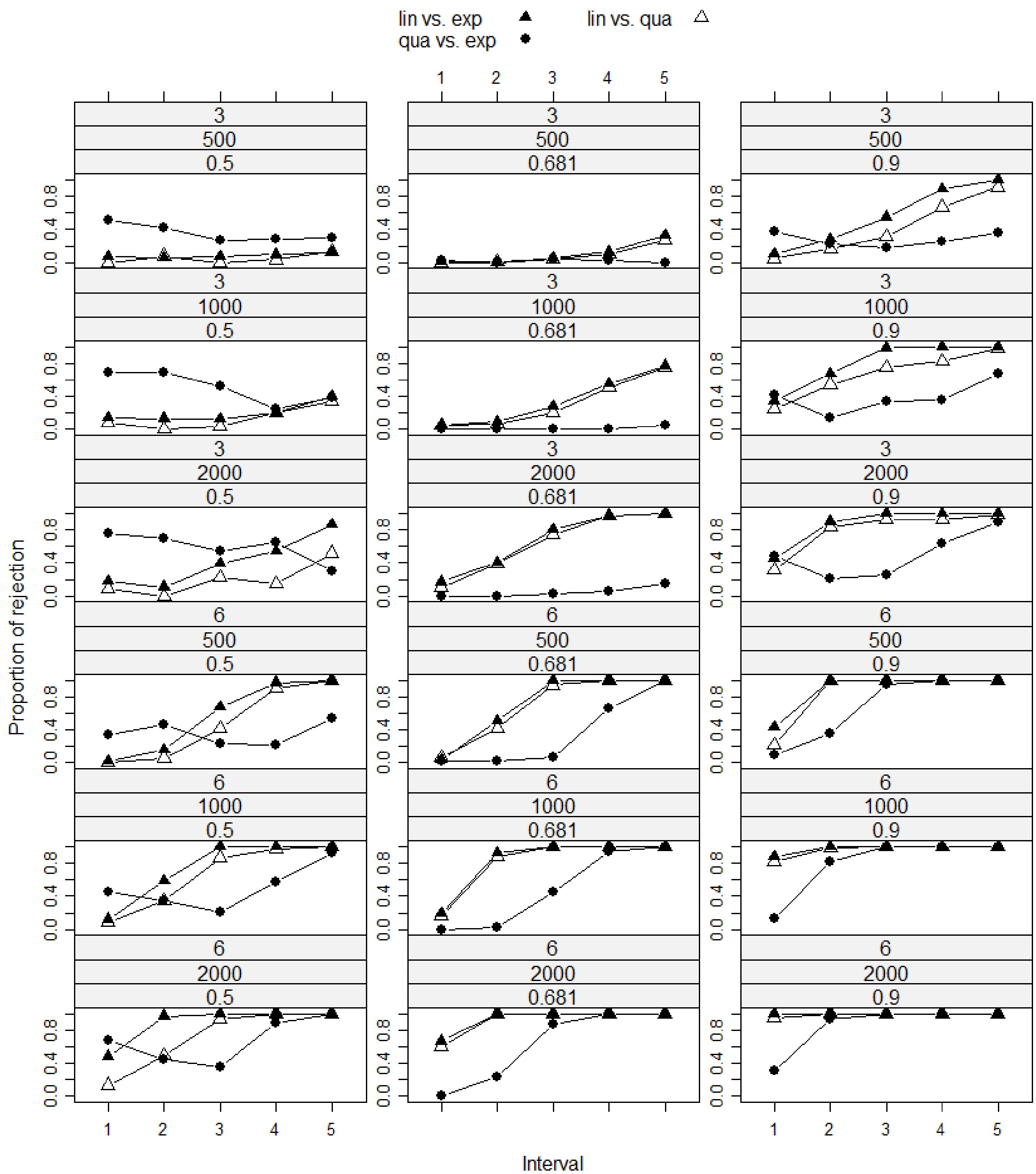
Supplementary Figure 3
Average number of acceptable solutions by interval width for $\gamma = 0.033$, separately for each model



Note. Rows 1, 2, 3: *T* = 3, rows 4, 5, 6: *T* = 6; Rows 1, 4: *N* = 500, rows 2, 5: *N* = 1000, rows 3, 6: *N* = 2000; Column 1: GCR = .500, column 2: GCR = .681, column 3: GCR = .900.

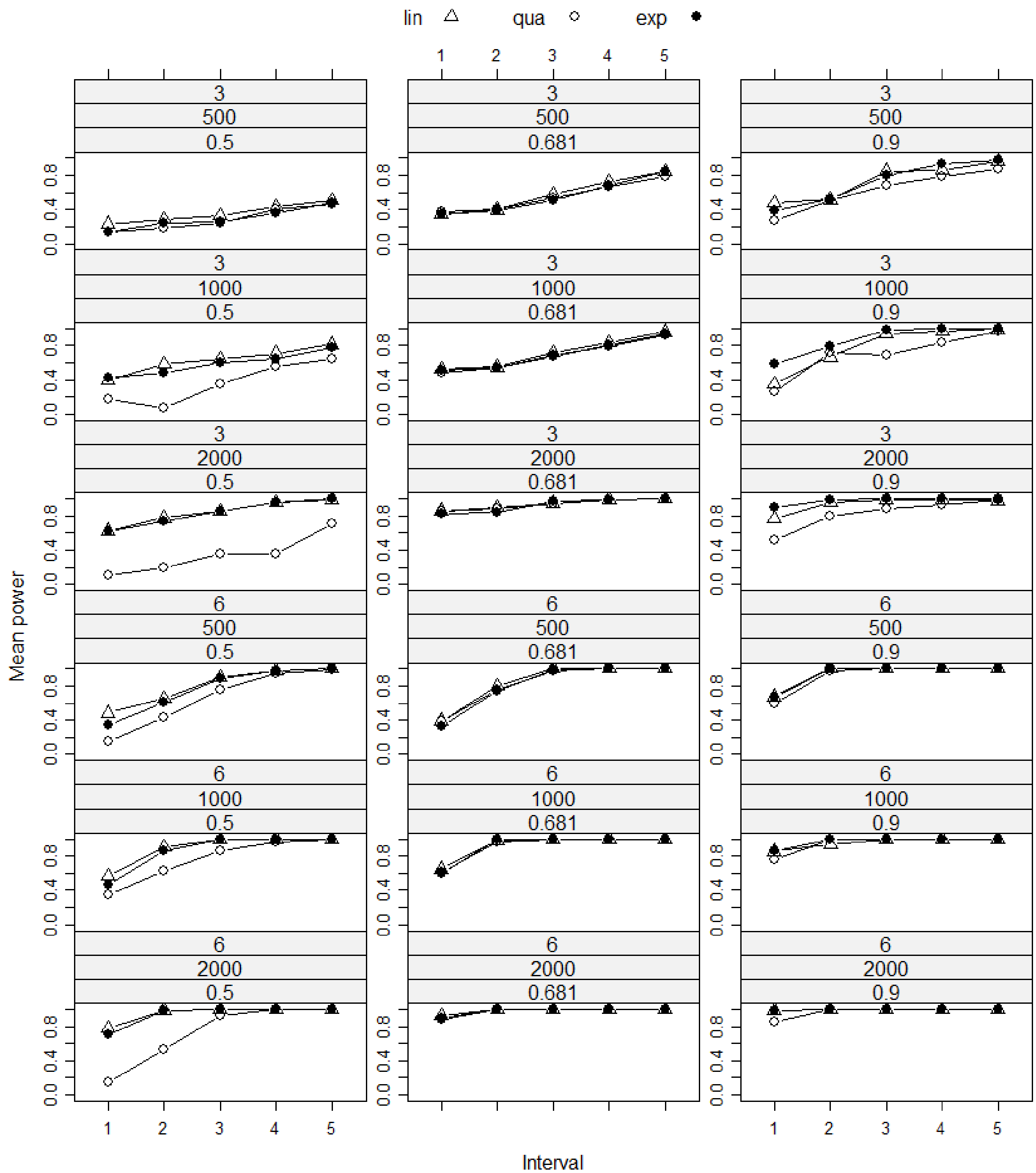
Supplementary Figure 4

Proportions of rejection of the linear GM and the quadratic GM when compared to the exponential GM and of the linear GM when compared to the quadratic GM (based on difference in BIC greater than 10) as a function of interval width for $\gamma = 0.033$ only



Note. Rows 1, 2, 3: $T = 3$, rows 4, 5, 6: $T = 6$; Rows 1, 4: $N = 500$, rows 2, 5: $N = 1000$, rows 3, 6: $N = 2000$; Column 1: GCR = .500, column 2: GCR = .681, column 3: GCR = .900.

Supplementary Figure 5
Power to Detect Variance in Change by Interval Width for $\gamma = 0.033$, for each Model



Note. Rows 1, 2, 3: $T = 3$, rows 4, 5, 6: $T = 6$; Rows 1, 4: $N = 500$, rows 2, 5: $N = 1000$, rows 3, 6: $N = 2000$; Column 1: GCR = .500, column 2: GCR = .681, column 3: GCR = .900.