A contrast of meta and metafor packages for meta-analyses in R

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Abstract

There is extensive choice in R to support meta-analyses. Two common packages used in the sciences include meta and metafor. A brief contrast of their strengths is described here for the synthesis scientist. Meta is a direct, intuitive choice for rapid implementation of general meta-analytical statistics. Metafor is a comprehensive package best suited for relatively more complex models. Both packages provide estimates of heterogeneity, excellent visualization tools, and functions to explore publication bias. Preference and specific needs will facilitate choice between these two options. Nonetheless, metafor has a steeper learning curve but greater rewards.

Keywords

contrasts, computational tools, Meta, meta-analyses, Metafor, methods, R, review

Introduction

Meta-analyses are common and powerful synthesis tools in science. Typically in the natural sciences, meta-analyses are used as a mechanism to describe and aggregate quantitative evidence from a set of peer-reviewed, primary research publications (Lortie and Bonte 2016; Nakagawa et al. 2017). A meta-analysis in the natural sciences, i.e. outside the health sciences, is comprised of a formalized systematic review and analysis of effect sizes and is termed a meta-analysis when statistics examining intervention efficacy are included (Lortie 2014). In other fields, the terms systematic review and meta-analysis are used more interchangeable, and meta-statistics are often done on compiled randomized controlled trials or other relatively large datasets in addition to data derived from peer-reviewed publications. The derived data in the natural sciences routinely extracts only the mean values or single point measures from publications (Stewart and Schmid 2015). The synthesis statistics were commonly done using MetaWin in some fields (Rosenberg, Adams, and Gurevitch 2000) or other GUI-based applications for a number of years. More recently however, statistics in the fields of ecology and evolution for instance have increasingly moved to the programming language R (Lai et al. 2019), and synthesis statistics are no exception. At least two R packages have risen to prominence for general meta-analytical statistics in the natural sciences - namely meta (Schwarzer 2019) and metafor (Viechtbauer 2017). Given that meta-analyses are also increasingly published in these same fields (Cadotte, Mehrkens, and Menge 2012; Lortie and Bonte 2016), a brief comment on the ecosystem of analytical choices that R provides is beneficial and timely. We need synthesis to inform evidence-based decisioning, and meta-analyses can be the primary tool if aggregated primary datasets are unavailable. Furthermore even with primary data in hand, data reduction to effect sizes within primary and synthesis studies is a mechanism to illustrate differences and strength of effects. These approaches provide the capacity for higher-order analyses and reuse (Gerstner et al. 2017) suggesting that familiarity with effect sizes is both germane and practical.

The R ecosystem for meta-analyses

Like many fundamental challenges in science, the R developer community provides potential solution sets distributed across multiple packages for synthesis. Broadly speaking, alternative packages in R sometimes examine an issue from different perspectives and provide unique functions. In other instances, packages can be very similar or analogs in terms of functionality and use conceptually aligned functions that differ only in nomenclature or arguments (Lortie et al. 2020). Scientific synthesists that choose to do a meta-analyses in R have options. A total of 63 packages associated with various aspects of conducting a meta-analysis have been identified in a comprehensive review and typology of options (Polanin, Hennessy, and Tanner-Smith 2016). Both meta (Schwarzer 2019) and metafor (Viechtbauer 2017) are amongst 11 generic packages identified (Polanin, Hennessy, and Tanner-Smith 2016). These two packages are analogs but with different inherent workflows. There is also rmeta for simple fixed and random effects meta-analyses (Lumley 2018), mada for diagnostics (Doebler 2017), (Doebler 2017), netmeta for frequentist network meta statistics (Rucker et al. 2019), and mvmeta for multivariate derived data aggregations (Gasparrini 2018) to name a few options. The latter three packages listed have distinct and specific niches for analysis whilst meta and metafor overlap considerably. Consequently, a brief contrast in facilitating choice between these two packages for the general analyst is provided here.

Contrast of meta versus metafor

Meta is a well-maintained, recently updated CRAN R package (Version 4.11-0 updated on Feb 20, 2020) with 31 unique functions, 7 sample datasets (Appendix A), and a reference manual. There is also an exceptional textbook devoted to meta-analysis in R that focuses primarily on this package (Schwarzer, Carpenter, and Rücker 2015). It is highly capable of resolving most general meta-analytical challenges that an analyst will face including the capacity to include Empirical Bayes estimators as arguments in some functions, predictive meta-statistics, interaction terms, meta-regression, and modifiers. Note that for some of these methods, the rma.uni function is sourced internally from the package metafor. This is intriguing but mostly opaque and inconsequential to the user if she prefers the structure of the arguments within functions, the semantics, or the workflow of the meta package. The primary strengths include its direct and straightforward implementation with minimal (source) lines of code to do an analysis. Provided one has secured the derived data from the studies and organized into a dataframe with vectors as each key argument within the main meta-model

fitting functions, statistics are simple. The type of response variable such as mean, continuous, or rate is matched to a specific function call such as metamean, metacont, or metarate. This is semantically intuitive and encourages good thinking before statistics because it engenders consideration of the data. The effect size calculation is included in this main function and defaults return the most prevalent effect size measure typically associated with those data, but it can also be specified as an argument. The primary workflow is thus a single step if the user elects to rely on the internal calculations provided in this package. Exploration of the model is well articulated with funnel, radial, and forest plots. Z-scores, significance tests, and heterogeneity statistics are printed in the model summary. Publication bias is also provided as a more in-depth function entitled metabias within this package. There are two standout functions in this package. The first is a function entitled metagen, and it is a backup, multipurpose tool so to speak that fits a generic inverse variance meta-analysis. This a handy tool for user-calculated effect size measures or for exploration of statistical trends with reduced data assumptions. In some fields, there are specific effect size estimates that this function provides a robust, easy-to-fit capacity for statistics. The second standout function is bubble.metareg for a quick, visual exploration of the outcome of a meta-regression. It is useful in contemporary data science to use visualization as a means to understand data (Lortie 2017), but statistical packages do not always provide the means to easily iterate between statistics or model fitting and visualization. In summary, excepting unique data or statistical issues, this package is directly implemented and effective.

Metafor is a more comprehensive package in many respects. This package includes 74 functions, 35 datasets (Appendix A), a vignette (Viechtbauer 2010), flowchart as secondary vignette (https://cran.r-project.org/web/packages/metafor/vignettes/diagram.pdf), and website (http://www.metafor-project.org/doku.php). The package was last updated on March 19, 2020 (Version 2.4-0). The text 'Meta-analysis with R' also describes implementation of this package (Schwarzer, Carpenter, and Rücker 2015) but to a lesser extent than meta. The depth of the package metafor provides greater capacities relative to the meta package but does come at the expense of a steeper initial learning curve. Completing a meta-analysis using this package requires an additional step, i.e. effect sizes must be calculated a priori, not within the model fitting process. This is facilitated with the standalone function escalc, and it can return a wide range of effect sizes measures. Thus, the two-step process begins with firstly compiling and aggregating the derived dataframe to an effect size table then secondly fitting a model. The data structure is also a bit more rigid for the model fitting, and the nomenclature for this subset of functions is written to parallel more traditional general linear model fitting from conventional statistics. This is both a strength and limitation because one must plan the model to fit in advance and learn the function and arguments, but it is also an advantage as well because model specification uses the familiar notation of tilde. Model fitting is based on the type of model in the call such a random or fixed effects and not on the type of the response data as in meta package. Here, it is more akin to conventional general linear model fitting for those familiar with these functions in R. If the model is more complex with moderators, then this can be directly included in the model fit here via a mods argument whereas in the meta package the model is updated with moderators in a subsequent step. This suggests that if moderators or covariates in the main model are likely relevant to the analyses, then metafor is a strong starting point. The model summary also prints Z-scores, significance tests, and two sets of heterogeneity estimates. Forest and radial plots are also provided as additional functions. Publication bias statistical estimator functions include trimfill and ranktest. Standout elements of this package include GOSH plots that provide a graphical display of study heterogeneity (Olkin, Dahabreh, and Trikalinos 2012) and the enhanced model fitting capacities such as the function fitstats that provides log-likelihood estimates and AIC or BIC scores on meta-analysis objects. This package requires a focus on model fitting, and while there is additional effort in specifying the data at the onset of the workflow, the rewards in subsequent tools to handle models are significant.

Conclusions

Statistics are sometimes about preferences and thinking styles (Hector 2017), and scientific synthesis is both an art and a science (Lortie and Bonte 2016). Trade-offs are also common in adopting one ecosystem, analysis tool, or specific package for data wrangling and analyses. If more rapid, less specified, general meta-analyses are the goal – the package meta is a direct means to an end. Moderators are added post hoc in additional, update model steps, but the first model fit is a single, intuitive process. Meta-regression is viable and interaction terms can be included. The generic meta-analysis function is a superb tool. Metafor requires

the effect size compilation a priori and is thus a bit more coding to prepare for the meta-model. However, deeper and more complex model fits are inherent in the semantics of these functions. If the synthesist does have not effect size measure in hand or wishes to calculate effect sizes measures but not for meta-models, the escalc function is invaluable in this package. In summary, both packages provide the capacity for basic and advanced meta-analyses but more advanced modelling is likely worth the commitment to metafor.

Table 1.

A contrast of meta and metafor using the critical principles developed in 'A checklist for choosing between R packages in ecology and evolution' (Lortie et al. 2020).

item	criteria	meta	metafor
1	maturity	fourth major version	third major version
2	active development	Schwarzer maintains website and GitHub repository	Viechtbauer maintains website and GitHub repository
3	recently updated	Feb 20, 2020	March 19, 2020
4	documentation available	reference manual	reference manual and two vignettes
5	published in similar projects	widespread use in ecology, evolution, and to a lesser extent the social sciences	widespread use in ecology, evolution, and the social sciences
6	license	GPL-2	GPL-2
7	semantics intuitive	functions to fit meta-analyses corresponds to data type intuitive	fitting meta-analyses logic is similar to GLM fitting in R
8	functions that get the job done	most major data types have a specific function and there is also a generalized metagen function	requires clear specification in arguments but rma function is a very general yet flexible tool
9	arguments to support your needs	there is an sm argument for specification of summary measures within meta-analysis functions	extensive breadth in capacity to specify model fitting
10	dependencies reasonable and reported	depends on R, and imports include grid, metafor, lme4, and CompQuadForm listed	depends on R, and imports include stats, utils, graphics, grDevices, and nlme

Appendix A.

A list of objects included in each package when loaded into the R environment.

package	object	role	type
meta	amlodipine	Amlodipine for Work Capacity	data
meta	cisapride	Cisapride in Non-Ulcer Dispepsia	data
meta	Fleiss93	Aspirin after Myocardial Infarction	data
meta	Fleiss93cont	Mental Health Treatment	data
meta	Olkin95	Thrombolytic Therapy after Acute Myocardial Infarction	data
meta	smoking	Smoking example	data
meta	woodyplants	Elevated CO_2 and total biomass of woody plants	data
meta	as.data.frame.meta	Additional functions for objects of class meta	function
meta	baujat	Baujat plot to explore heterogeneity in meta-analysis	function
meta	bubble	Bubble plot to display the result of a meta-regression	function
meta	ci	Calculation of confidence intervals (based on normal...	function
meta	forest	Forest plot to display the result of a meta-analysis	function
meta	funnel	Plot to assess funnel plot asymmetry	function
meta	gs	Get default for a meta-analysis setting.	function
meta	labbe	L'Abbe plot for meta-analysis with binary outcomes	function
meta	metabias	Test for funnel plot asymmetry	function
meta	metabin	Meta-analysis of binary outcome data	function
meta	metabind	Combine meta-analysis objects	function
meta	metacont	Meta-analysis of continuous outcome data	function
meta	metacor	Meta-analysis of correlations	function
meta	metacr	Meta-analysis of outcome data from Cochrane review	function
meta	metacum	Cumulative meta-analysis	function
meta	metagen	Generic inverse variance meta-analysis	function
meta	metainc	Meta-analysis of incidence rates	function
meta	metainf	Influence analysis in meta-analysis using leave-one-out...	function
meta	metamean	Meta-analysis of single means	function
meta	meta-package	meta: Brief overview of methods and general hints	function

(continued)

package	object	role	type
meta	metaprop	Meta-analysis of single proportions	function
meta	metarate	Meta-analysis of single incidence rates	function
meta	metareg	Meta-regression	function
meta	print.meta	Print and summary method for objects of class meta	function
meta	print.rm5	Print and summary methods for objects of class rm5	function
meta	read.mtv	Import RevMan 4 data files (.mtv)	function
meta	read.rm5	Import RevMan 5 data files (.csv)	function
meta	settings.meta	Print and change default settings to conduct and print or...	function
meta	trimfill	Trim-and-fill method to adjust for bias in meta-analysis	function
meta	update.meta	Update a meta-analysis object	function
meta	weights.meta	Calculate absolute and percentage weights for meta-analysis	function
metafor	dat.bangertdrowns2004	Studies on the Effectiveness of Writing-to-Learn...	data
metafor	dat.begg1989	Studies on Bone-Marrow Transplantation versus Chemotherapy...	data
metafor	dat.berkey1998	Studies on Treatments for Periodontal Disease	data
metafor	dat.bonett2010	Studies on the Reliability of the CES-D Scale	data
metafor	dat.bourassa1996	Studies on the Association between Handedness and...	data
metafor	dat.colditz1994	Studies on the Effectiveness of the BCG Vaccine Against...	data
metafor	dat.collins1985a	Studies on the Treatment of Upper Gastrointestinal Bleeding...	data
metafor	dat.collins1985b	Studies on the Effects of Diuretics in Pregnancy	data
metafor	dat.curtis1998	Studies on the Effects of Elevated CO2 Levels on Woody Plant...	data
metafor	dat.debruin2009	Studies on Standard Care Quality and HAART-Adherence	data
metafor	dat.egger2001	Studies on the Effectiveness of Intravenous Magnesium in...	data
metafor	dat.fine1993	Studies on Radiation Therapy with or without Adjuvant...	data

(continued)

package	object	role	type
metafor	dat.gibson2002	Studies on the Effectiveness of Self-Management Education and...	data
metafor	dat.hackshaw1998	Studies on Lung Cancer Risk from ETS Exposure	data
metafor	dat.hart1999	Studies on the Effectiveness of Warfarin for Preventing...	data
metafor	dat.hasselblad1998	Studies on the Effectiveness of Counseling for Smoking...	data
metafor	dat.hine1989	Studies on Prophylactic Use of Lidocaine After a Heart Attack	data
metafor	dat.ishak2007	Studies on Deep-Brain Stimulation	data
metafor	dat.konstantopoulos2011	Studies on the Effects of Modified School Calendars on...	data
metafor	dat.laopaiboon2015	Studies on the Effectiveness of Azithromycin for Treating...	data
metafor	dat.lee2004	Studies on Acupoint P6 Stimulation for Preventing Nausea	data
metafor	dat.li2007	Studies on the Effectiveness of Intravenous Magnesium in...	data
metafor	dat.linde2005	Studies on the Effectiveness of St. John's Wort for Treating...	data
metafor	dat.mcdaniel1994	Studies on the Validity of Employment Interviews	data
metafor	dat.molloy2014	Studies on the Relationship between Conscientiousness and...	data
metafor	dat.nielweise2007	Studies on Anti-Infective-Treated Central Venous Catheters...	data
metafor	dat.nielweise2008	Studies on Anti-Infective-Treated Central Venous Catheters...	data
metafor	dat.normand1999	Studies on the Length of Hospital Stay of Stroke Patients	data
metafor	dat.pagliaro1992	Studies on the Effectiveness of Nonsurgical Treatments in...	data
metafor	dat.pignon2000	Studies on the Effectiveness of Locoregional Treatment plus...	data
metafor	dat.pritz1997	Studies on the Effectiveness of Hyperdynamic Therapy for...	data
metafor	dat.raudenbush1985	Studies on Assessing the Effects of Teacher Expectations on...	data
metafor	dat.riley2003	Studies on MYC-N as a Prognostic Marker for Neuroblastoma	data
metafor	dat.senn2013	Studies on the Effectiveness of Glucose-Lowering Agents	data

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package	object	role	type
metafor	dat.yusuf1985	Studies of Beta Blockers During and After Myocardial...	data
metafor	addpoly	Add Polygons to Forest Plots	function
metafor	addpoly.default	Add Polygons to Forest Plots (Default Method)	function
metafor	addpoly.rma	Add Polygons to Forest Plots (Method for 'rma' Objects)	function
metafor	anova.rma	Likelihood Ratio and Wald-Type Tests for 'rma' Objects	function
metafor	baujat	Baujat Plots for 'rma' Objects	function
metafor	bldiag	Construct Block Diagonal Matrix	function
metafor	blup	Best Linear Unbiased Predictions for 'rma.uni' Objects	function
metafor	coef.permutest.rma.uni	Extract the Model Coefficient Table from 'permutest.rma.uni'...	function
metafor	coef.rma	Extract the Model Coefficients and Coefficient Table from...	function
metafor	confint.rma	Confidence Intervals for 'rma' Objects	function
metafor	cumul	Cumulative Meta-Analysis for 'rma' Objects	function
metafor	escalc	Calculate Effect Sizes and Outcome Measures	function
metafor	fitstats	Fit Statistics and Information Criteria for 'rma' Objects	function
metafor	fitted.rma	Fitted Values for 'rma' Objects	function
metafor	forest	Forest Plots	function
metafor	forest.cumul.rma	Forest Plots (Method for 'cumul.rma' Objects)	function
metafor	forest.default	Forest Plots (Default Method)	function
metafor	forest.rma	Forest Plots (Method for 'rma' Objects)	function
metafor	fsn	Fail-Safe N Analysis (File Drawer Analysis)	function
metafor	funnel	Funnel Plots	function
metafor	gosh	GOSH Plots for 'rma' Objects	function
metafor	hc	Meta-Analysis based on the Method by Henmi and Copas (2010)	function
metafor	influence.rma.mv	Outlier and Influential Case Diagnostics for 'rma.mv' Objects	function
metafor	influence.rma.uni	Outlier and Influential Case Diagnostics for 'rma.uni'...	function
metafor	labbe	L'Abbe Plots for 'rma' Objects	function
metafor	leave1out	Leave-One-Out Diagnostics for 'rma' Objects	function
metafor	llplot	Likelihood Plot of a Parameter Corresponding to an Effect...	function

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package	object	role	type
metafor	metafor.news	Read News File of the Metafor Package	function
metafor	metafor-package	metafor: A Meta-Analysis Package for R	function
metafor	methods.escalc	Methods for 'escalc' Objects	function
metafor	methods.list.rma	Methods for 'list.rma' Objects	function
metafor	model.matrix.rma	Model Matrix for 'rma' Objects	function
metafor	permutest	Permutation Tests for 'rma.uni' Objects	function
metafor	plot.cumul.rma	Plot Method for 'cumul.rma' Objects	function
metafor	plot.gosh.rma	Plot Method for 'gosh.rma' Objects	function
metafor	plot.infl.rma.uni	Plot Method for 'infl.rma.uni' Objects	function
metafor	plot.rma	Plot Method for 'rma' Objects	function
metafor	predict.rma	Predicted Values for 'rma' Objects	function
metafor	print.anova.rma	Print Method for 'anova.rma' Objects	function
metafor	print.confint.rma	Print Methods for 'confint.rma' and 'list.confint.rma'...	function
metafor	print.escalc	Print and Summary Methods for 'escalc' Objects	function
metafor	print.fsn	Print Method for 'fsn' Objects	function
metafor	print.gosh.rma	Print Method for 'gosh.rma' Objects	function
metafor	print.hc.rma.uni	Print Method for 'hc.rma.uni' Objects	function
metafor	print.list.rma	Print method for 'list.rma' Objects	function
metafor	print.permutest.rma.uni	Print Method for 'permutest.rma.uni' Objects	function
metafor	print.ranktest.rma	Print Method for 'ranktest.rma' Objects	function
metafor	print.regtest.rma	Print Method for 'regtest.rma' Objects	function
metafor	print.rma	Print and Summary Methods for 'rma' Objects	function
metafor	print.robust.rma	Print Method for 'robust.rma' Objects	function
metafor	profile.rma	Profile Plots for 'rma' Objects	function
metafor	qqnorm.rma	Normal QQ Plots for 'rma' Objects	function
metafor	radial	Radial (Galbraith) Plots for 'rma' Objects	function

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package	object	role	type
metafor	ranef	Best Linear Unbiased Predictions for 'rma.uni' and 'rma.mv'...	function
metafor	ranktest	Rank Correlation Test for Funnel Plot Asymmetry	function
metafor	regtest	Regression Test for Funnel Plot Asymmetry	function
metafor	replmiss	Replace Missing Values in a Vector	function
metafor	reporter	Dynamically Generated Analysis Reports for 'rma.uni' Objects	function
metafor	residuals.rma	Residual Values based on 'rma' Objects	function
metafor	rma.glmm	Meta-Analysis via Generalized Linear (Mixed-Effects) Models	function
metafor	rma.mh	Meta-Analysis via the Mantel-Haenszel Method	function
metafor	rma.mv	Meta-Analysis via Multivariate/Multilevel Linear...	function
metafor	rma.peto	Meta-Analysis via Peto's Method	function
metafor	rma.uni	Meta-Analysis via Linear (Mixed-Effects) Models	function
metafor	robust	(Cluster) Robust Tests and Confidence Intervals for 'rma'...	function
metafor	simulate.rma	Simulate Method for 'rma' Objects	function
metafor	to.long	Convert Data from Vector to Long Format	function
metafor	to.table	Convert Data from Vector to Table Format	function
metafor	transf	Transformation Function	function
metafor	trimfill	Trim and Fill Analysis for 'rma.uni' Objects	function
metafor	update.rma	Model Updating for 'rma' Objects	function
metafor	vcov.rma	Extract Various Types of Variance-Covariance Matrices from...	function
metafor	vif	Variance Inflation Factors for 'rma' Objects	function
metafor	weights.rma	Compute Weights for 'rma' Objects	function

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