

Meta-Analytic Evaluation of Inhibitory Control Training with Computerized Applications: A Stata Implementation

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Outline

Introduction

- Inhibitory control training
- Objectives of the study

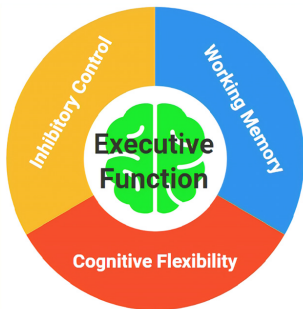
Method

- Literature review
- Study selection and data extraction
- Meta-analysis workflow

Results

- Compute effect sizes
- Obtain meta-analysis summary
- Explore heterogeneity
- Publication bias detection
- Explore moderators of effect size
- Advanced models in meta-analysis

Executive Functions and Cognitive Training



Core Components of Executive Function



Inhibitory Control Training

Inhibitory Control: Why It Matters

- ▶ Inhibitory control is a core executive function essential for:
 - ▶ Behavioral regulation
 - ▶ Decision-making
 - ▶ Adaptation to changing environments
- ▶ Widely studied in cognitive and clinical research (e.g., ADHD, addiction).
- ▶ Meta-analyses in addiction contexts show moderate effects of inhibitory training.
- ▶ However, its generalizability to broader cognitive domains (e.g., cognitive flexibility) is uncertain.

Why a Meta-Analysis Now?

- ▶ Research on working memory training has yielded robust findings.
- ▶ Less is known about the transfer effects of inhibitory control training:
 - ▶ **Near transfer:** to structurally similar cognitive tasks.
 - ▶ **Far transfer:** to broader cognitive functions (e.g., cognitive flexibility, working memory).
- ▶ This meta-analysis evaluates whether computerized inhibitory control training yields significant improvements.

Objectives of the Study

- ▶ To quantify the effect of computerized inhibitory control training across:
 1. Inhibitory control tasks
 2. Cognitive flexibility
 3. Working memory
- ▶ To explore the utility of **Stata's meta-analysis framework** in cognitive neuroscience.
- ▶ To identify potential moderators (e.g., age, gender, time duration, money compensation).

Inclusion Criteria (PRISMA)

- ▶ The review followed PRISMA guidelines (Moher et al., 2009; Page et al., 2021).
- ▶ Protocol registered in PROSPERO. Data available on OSF.
- ▶ Inclusion criteria:
 - ▶ Randomized Controlled Trials (RCT)
 - ▶ Experimental and control groups
 - ▶ Pre/post cognitive behavioral assessments
 - ▶ Main intervention targeting **inhibitory control**
 - ▶ Computerized delivery (standard or gamified)
 - ▶ Published in English
- ▶ Final sample: **12 studies** (2004–2024)

Search Strategy

- ▶ Databases searched: Web of Science, Scopus, PsycArticles, PubMed, Cochrane Library
- ▶ Timeframe: January 2004–December 2024
- ▶ Search terms:
 - ▶ "Stroop" OR "Stop signal" OR "Go no-go" OR "Simon" OR "Flanker" OR "Antisaccades"
 - ▶ AND "Inhibitory Control" AND "RCT" AND "Cognitive Training"
- ▶ Manual screening of references from previous meta-analyses
- ▶ Duplicates removed using Zotero
- ▶ Screening and full-text review by two independent coders

Study Selection Process (PRISMA Diagram)

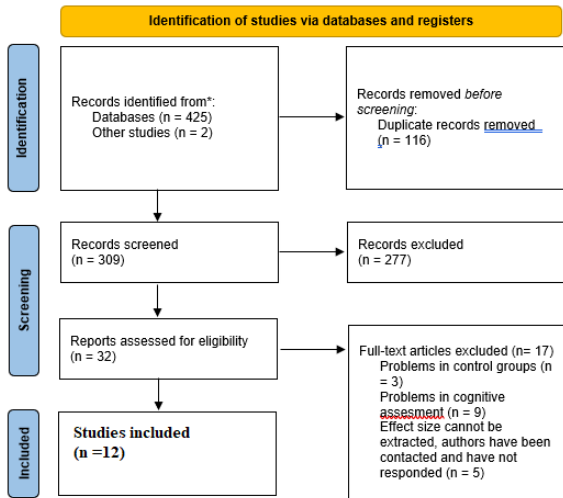


Figure: Flow diagram of study selection following PRISMA guidelines.

Data Extraction

- ▶ Standardized coding protocol:
 - ▶ Study info: authors, year, journal, country
 - ▶ Design: sample sizes, type of intervention/control, task used
 - ▶ Participants: age, % women, individual characteristics
 - ▶ Training: duration in weeks, session length (minutes)
 - ▶ Outcomes: means, SDs, N per group
- ▶ Dual coding: extracted by DO and verified by DA
- ▶ Coding included all pre/post behavioral evaluations
- ▶ Risk of Bias Assessment applied to all 12 included studies using the **RoB 2 tool** Sterne (2019).

Meta-Analysis Workflow (Stata)

Key steps according to Stata's meta [▶ Reference](#)

- ▶ **Prepare your data for meta-analysis**

Structure data following PRISMA guidelines and pre-registered protocols (e.g., PROSPERO).

- ▶ **Obtain meta-analysis summary**

Compute effect sizes (Hedges' g) and perform a global meta-analysis (Fixed or REML models).

- ▶ **Explore heterogeneity**

Assess between-study variability using Q , I^2 , τ^2 , and subgroup/meta-regression analyses.

- ▶ **Investigate small-study effects and publication bias**

Use funnel plots and regression-based tests (e.g., Egger's test) to evaluate bias.

Implemented using `meta` and `meangain_effect` packages in Stata

Prepare your data for meta-analysis and compute effect sizes

Stata syntax examples

- ▶ **Use stored effect sizes and SEs:**

```
. meta set es se
```

Or compute effect sizes from summary data:

- ▶ *Two-sample binary data (log odds-ratios):*

```
. meta esize n11 n12 n21 n22, esize(lnoratio)
```

- ▶ *Two-sample continuous data (Hedges's g):*

```
. meta esize n1 mean1 sd1 n2 mean2 sd2,  
esize(hedgesg)
```

- ▶ *One-sample binary data (Freeman–Tukey proportions):*

```
. meta esize nsucc ssize, esize(ftukeyprop)
```

- ▶ *Correlation data (Fisher's z):*

```
. meta esize rho ssize, fisherz
```

Source: *Stata Meta-Analysis Overview*

Meta-Analysis Setup in Stata GUI

meta - Meta-Analysis Control Panel

Clear meta settings Display meta settings Modify meta settings

Setup

Summary

Forest plot

Heterogeneity

Regression

Publication bias

Multivariate

Multilevel

Note: Multivariate and multilevel meta-analyses do not require any setup. Proceed to the respective pane: Multivariate or Multilevel.

Declare meta-analysis data

☒ Compute and declare effect sizes for two-group comparison of continuous outcomes

☐ Compute and declare effect sizes for two-group comparison of binary outcomes

☐ Compute and declare effect sizes for estimating a single proportion (prevalence)

☐ Compute and declare effect sizes for correlations data

☐ Declare generic, precomputed effect sizes (in the metric closest to normality)

Main if/in Model Options

Specify group 1 (treatment) variables

Sample size: Mean: Standard deviation:

Specify group 2 (control) variables

Sample size: Mean: Standard deviation:

Specify effect size

Effect size:

Hedges's g

☐ Use exact computation for the bias-correction factor

☐ Use Hedges and Olkin standard error for effect size

Submit

No. of studies: <none> Model: <none> Effect size: <none>
CI level: <none> Method: <none> Std. err.: <none>

Close

Graphical interface for specifying meta-analysis effect sizes and data structure in Stata.

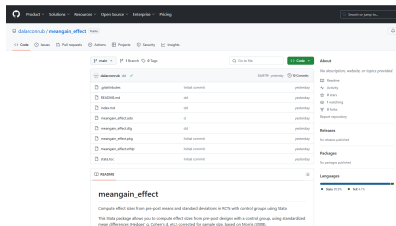
Mean Gain Effect Sizes Computation

- ▶ Effect sizes computed as **Hedges' g** and SE:
 - ▶ Based on pre/post means and SDs for experimental and control groups.
 - ▶ Standardized mean difference with small sample correction (Botella and Sánchez-Meca, 2015; Morris, 2008).
- ▶ Implemented using the `meangain_effect` Stata package, developed by the authors to compute effect sizes from gain scores in pre-post RCTs.
 - ▶ 📄 **Install from GitHub repository:**
`dalarconrub.github.io/meangain_effect/`
 - ▶ **Source code:** `github.com/dalarconrub/meangain_effect`
- ▶

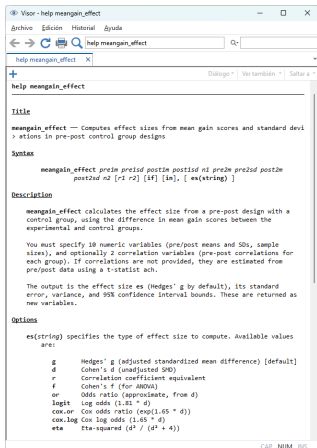
```
. meangain_effect pre1mean pre1sd post1mean  
post1sd n1 pre2mean pre2sd post2mean post2sd n2  
[r1 r2], es(g)
```

Compute Effect Size from Mean Gain Scores

User Package meangain_effect



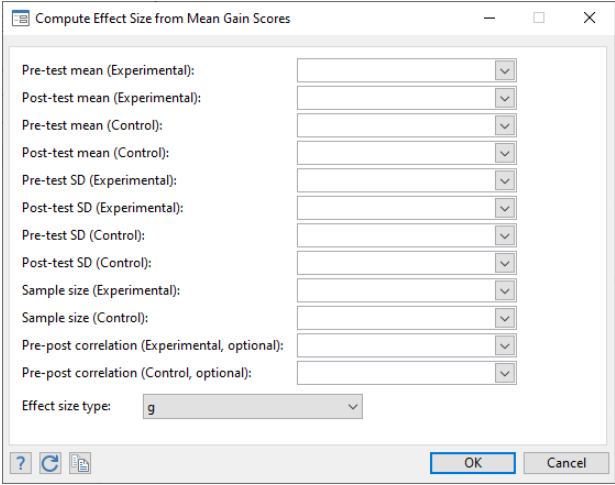
Install from GitHub repository:
dalarconrub/meangain_effect



Help information:
. help meangain_effect

Compute Effect Size from Mean Gain Scores

```
. db meangain_effect
```



The dialog box is titled "Compute Effect Size from Mean Gain Scores". It contains several input fields, each with a dropdown arrow on the right. The fields are arranged in two columns. The first column contains: "Pre-test mean (Experimental):", "Post-test mean (Experimental):", "Pre-test mean (Control):", "Post-test mean (Control):", "Pre-test SD (Experimental):", "Post-test SD (Experimental):", "Pre-test SD (Control):", "Post-test SD (Control):", "Sample size (Experimental):", "Sample size (Control):", "Pre-post correlation (Experimental, optional):", and "Pre-post correlation (Control, optional):". The second column contains: "Pre-test mean (Experimental):", "Post-test mean (Experimental):", "Pre-test mean (Control):", "Post-test mean (Control):", "Pre-test SD (Experimental):", "Post-test SD (Experimental):", "Pre-test SD (Control):", "Post-test SD (Control):", "Sample size (Experimental):", "Sample size (Control):", "Pre-post correlation (Experimental, optional):", and "Pre-post correlation (Control, optional):". At the bottom left, there is a label "Effect size type:" followed by a dropdown menu showing "g". At the bottom right, there are two buttons: "OK" and "Cancel".

Compute Effect Size from Mean Gain Scores

Pre-test mean (Experimental):

Post-test mean (Experimental):

Pre-test mean (Control):

Post-test mean (Control):

Pre-test SD (Experimental):

Post-test SD (Experimental):

Pre-test SD (Control):

Post-test SD (Control):

Sample size (Experimental):

Sample size (Control):

Pre-post correlation (Experimental, optional):

Pre-post correlation (Control, optional):

Effect size type: g

OK Cancel

Stata dialog for computing Effect Sizes from pre- and post-test means and standard deviations.

Obtain Meta-Analysis Summary

Estimate overall effect size and explore heterogeneity

- ▶ Estimate the overall effect size and its confidence interval:
 - ▶ `. meta summarize`
- ▶ Obtain heterogeneity statistics:
 - ▶ Between-study variance (τ^2), Cochran's Q, and I^2
- ▶ Produce a forest plot to visualize individual and pooled effect sizes:
 - ▶ `. meta forestplot`

Obtain Meta-Analysis Summary

```
. meta summarize
```

Effect-size label: Effect size

Effect size: **es**

Std. err.: **se**

Meta-analysis summary

Random-effects model

Method: REML

Number of studies = **12**

Heterogeneity:

tau2 = **0.0505**

I2 (%) = **37.08**

H2 = **1.59**

Study	Effect size	[95% conf. interval]		% weight
Study 1	0.147	-0.458	0.753	8.20
Study 2	0.632	0.165	1.099	11.16
Study 3	0.804	0.104	1.504	6.72
Study 4	0.712	0.251	1.173	11.32
Study 5	0.157	-0.188	0.502	14.68
Study 6	0.503	-0.090	1.095	8.43
Study 7	-0.710	-1.649	0.228	4.28
Study 8	0.580	0.030	1.131	9.25
Study 9	0.060	-0.512	0.632	8.82
Study 10	1.266	0.482	2.050	5.69
Study 11	0.239	-0.628	1.107	4.86
Study 12	0.778	0.068	1.488	6.58
theta	0.446	0.232	0.661	

Test of theta = 0: z = **4.08**

Prob > |z| = **0.0000**

Test of homogeneity: Q = chi2(11) = **19.59**

Prob > Q = **0.0513**

Overall Meta-Analytic Effect

- ▶ **12 independent comparisons** across studies
- ▶ Total of **648 participants**
- ▶ Overall effect size:

Hedges' $g = 0.446$, 95% CI [0.232, 0.661], $p < .001$

- ▶ Interpretation:
 - ▶ Moderate statistically significant effect
 - ▶ Suggests training improves cognitive performance
- ▶ Heterogeneity was low to moderate: $\tau^2 = 0.0505$, $I^2 = 37.08\%$, suggesting some variability across studies.
- ▶ The test for heterogeneity ($Q = 19.59, p = 0.051$) was marginally non-significant.

Forest Plot Dialog in Stata GUI

meta - Meta-Analysis Control Panel

Clear meta settings Display meta settings Modify meta settings

Setup
Summary
Forest plot
Heterogeneity
Regression
Publication bias
Multivariate
Multilevel

Forest plot

Main if/in Options Maximization Forest plot

Meta-analysis model

☒ Declared model
☐ Random effects
☐ Common effect
☐ Fixed effects

☐ Subgroup meta-analysis

Variables:
[Dropdown]

☐ Cumulative meta-analysis

Order variable: [Dropdown] Sort order: [Ascending] Stratify on variable: [Dropdown]

☐ Leave-one-out meta-analysis

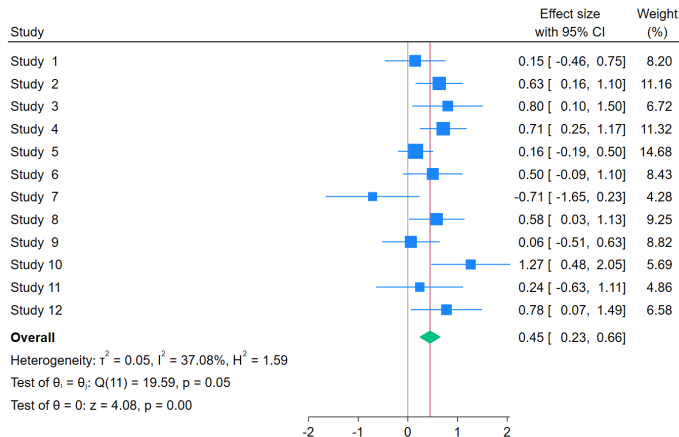
Submit

No. of studies: 12 Model: Random effects Effect size: es, Effect size
CI level: 95% Method: REML Std. err.: se

? [Refresh] Close

Forest Plot: Explore Heterogeneity

. meta forestplot



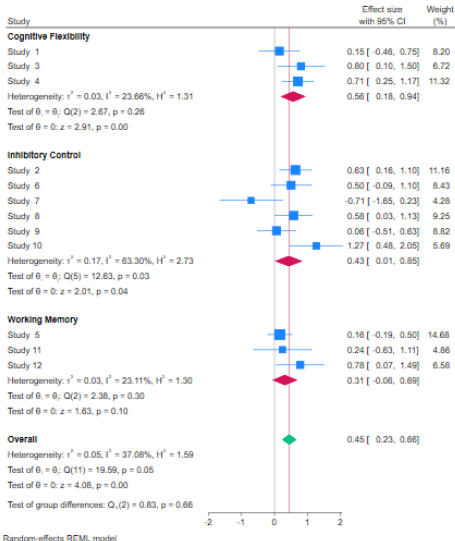
Random-effects REML model

Subgroup Forest Plot by Outcome Task

- ▶ Cognitive tasks grouped into three categories:
 1. Inhibitory Control
 2. Working memory
 3. Cognitive flexibility

Subgroup Forest Plot by Outcome Task

. meta forestplot, subgroup(Dimension)



Subgroup Analysis Results

Effect sizes by cognitive domain

► Cognitive Flexibility:

- Pooled effect size: $g = 0.56$, 95% CI [0.18, 0.94], **significant**.
- Low heterogeneity: $I^2 = 23.66\%$, $Q(2) = 2.67$, $p = 0.26$.

► Inhibitory Control:

- Pooled effect size: $g = 0.43$, 95% CI [0.01, 0.84], **significant**.
- Moderate heterogeneity: $I^2 = 63.30\%$, $Q(4) = 10.95$, $p = 0.02$.

► Working Memory:

- Pooled effect size: $g = 0.31$, 95% CI [-0.06, 0.69], *not significant*.
- Moderate heterogeneity: $I^2 = 23.11\%$, $Q(2) = 2.38$, $p = 0.30$.

► Test of subgroup differences: $Q_b(2) = 0.83$, $p = 0.66$ — no significant difference between domains.

Galbraith plot for publication bias detection

Galbraith Plot Settings (Stata GUI)

meta - Meta-Analysis Control Panel

Clear meta settings Display meta settings Modify meta settings

Setup
Summary
Forest plot
Heterogeneity
Regression
Publication bias
Multivariate
Multilevel

Heterogeneity
☒ Galbraith plot ☐ L'Abbe plot for binary data

Main if/in

Galbraith plot for summarizing meta-analysis

Meta-analysis model
☒ Default model
☐ Random effects
☐ Common effect
☐ Fixed effects

Options
☐ Suppress the regression line
☐ Suppress confidence intervals
95 Confidence level
☐ Suppress output for meta setting information
Graph options

Note: Also see "Regression" for using meta-regression to account for heterogeneity.

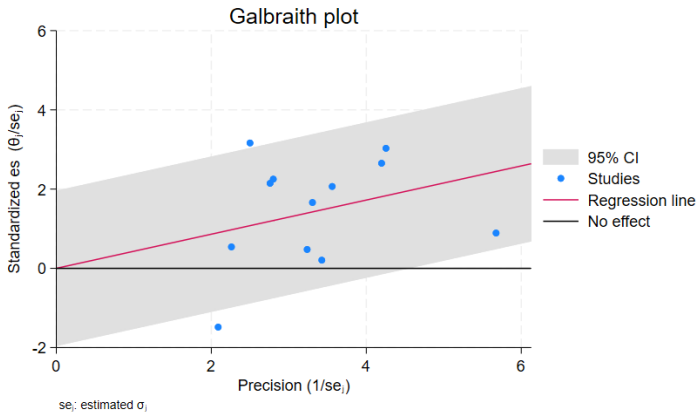
Submit

No. of studies: 12 Model: Random effects Effect size: es, Effect size
CI level: 95% Method: REML Std. err.: se

? Close

Galbraith plot for publication bias detection

```
. meta galbraith
```



Galbraith plot for publication bias detection

- ▶ The Galbraith plot displays standardized effect sizes (θ/SE_i) against precision ($1/SE_i$).
- ▶ The shaded area shows the 95% confidence interval around the regression line.
- ▶ Most points fall within the expected bounds, suggesting no major publication bias or influential outliers.

Funnel Plot for Publication Bias (Stata GUI)

meta - Meta-Analysis Control Panel

Clear meta settings Display meta settings Modify meta settings

Setup

Summary

Forest plot

Heterogeneity

Regression

Publication bias

Multivariate

Multilevel

Publication bias

☒ Funnel plot for graphical diagnostics of small-study effects
☐ Tests for small-study effects in meta-analysis
☐ Nonparametric trim-and-fill analysis of publication bias

Main if/in Model Options

☐ Produce separate plot by group

Grouping variables

By options

Specify y-axis metric:
Standard error

95 Confidence level

300 Number of points at which to evaluate the CIs

☐ Suppress meta settings information

Graph options *

Submit

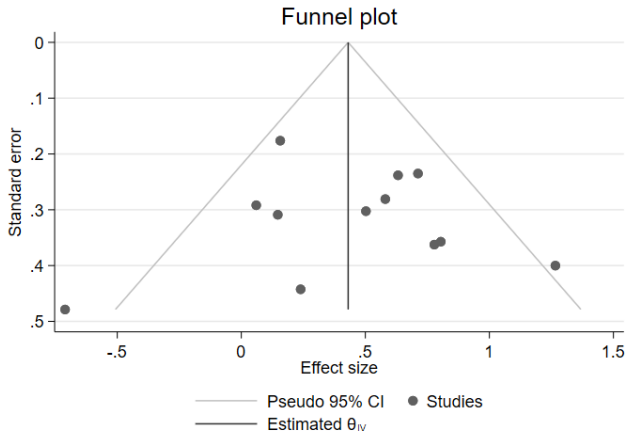
No. of studies: 12 Model: Random effects Effect size: es, Effect size
CI level: 95% Method: REML Std. err.: se

? 

Close

Funnel Plot for Publication Bias

```
. meta funnelplot, scheme(stsj)
```



Funnel Plot for Publication Bias

- ▶ The funnel plot shows the distribution of effect sizes (horizontal axis) against their standard errors (vertical axis).
- ▶ The studies appear symmetrically distributed around the pooled effect size ($\hat{\theta}_{IV}$), suggesting no strong evidence of publication bias.
- ▶ This visual impression is consistent with Egger's test ($p > 0.05$, non-significant).

Meta-Regression Analysis (Stata GUI)

Exploring moderators of effect size

meta - Meta-Analysis Control Panel

Clear meta settings Display meta settings Modify meta settings

Setup
Summary
Forest plot
Heterogeneity
Regression
Publication bias
Multivariate
Multilevel

Meta-regression

Model if/in Reporting Maximization Postestimation

Moderators

Specify moderators:
M_Age Femalepercentage Totalminutes MoneyCompensation

☒ Suppress constant term
☐ Fit constant-only model

Meta-analysis model

☒ Declared model
☐ Random effects
☐ Fixed effects

☐ Fit multiplicative error model
☐ Report t tests instead of z tests for coefficients

Submit

No. of studies: 12 Model: Random effects Effect size: es, Effect size
CI level: 95% Method: REML Std. err.: se

Close

Meta-Regression Results

Exploring moderators of effect size

```
. meta regress M_Age Femalepercentage Totalminutes MoneyCompensation, noconstant
```

Effect-size label: Effect size

Effect size: es

Std. err.: se

Random-effects meta-regression

Method: REML

Number of obs = 12

Residual heterogeneity:

tau2 = .1277

I2 (%) = 57.36

H2 = 2.35

R-squared (%) = 0.00

Wald chi2(4) = 10.65

Prob > chi2 = 0.0308

_meta_es	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
M_Age	-.0006669	.0065918	-0.10	0.919	-.0135866	.0122528
Femalepercentage	.0043892	.0047249	0.93	0.353	-.0048714	.0136498
Totalminutes	.0005336	.0003886	1.37	0.170	-.000228	.0012952
MoneyCompensation	-.028661	.3235827	-0.09	0.929	-.6628714	.6055495

Test of residual homogeneity: Q_res = chi2(8) = 17.86 Prob > Q_res = 0.0223

Meta-Regression Results

Exploring moderators of effect size

- ▶ None of the moderators (Mean Age, Female %, Minuts, Compensation) showed significant effects on the estimated effect size ($p > 0.05$).
- ▶ Residual heterogeneity remained substantial: $\tau^2 = 0.1277$, $I^2 = 57.36\%$.
- ▶ The model explained 0% of variance ($R^2 = 0.00$); residual heterogeneity was significant ($Q_{\text{res}}(8) = 17.86$, $p = 0.0223$).

Postestimation: Bubble plot

Meta-regression with one continuous variable

```
. meta regress SessiondurationWeeks
```

```
Effect-size label: Effect size
```

```
Effect size: es
```

```
Std. err.: se
```

```
Random-effects meta-regression
```

```
Method: REML
```

```
Number of obs = 12
```

```
Residual heterogeneity:
```

```
tau2 = .05524
```

```
I2 (%) = 39.29
```

```
H2 = 1.65
```

```
R-squared (%) = 0.00
```

```
Wald chi2(1) = 1.13
```

```
Prob > chi2 = 0.2873
```

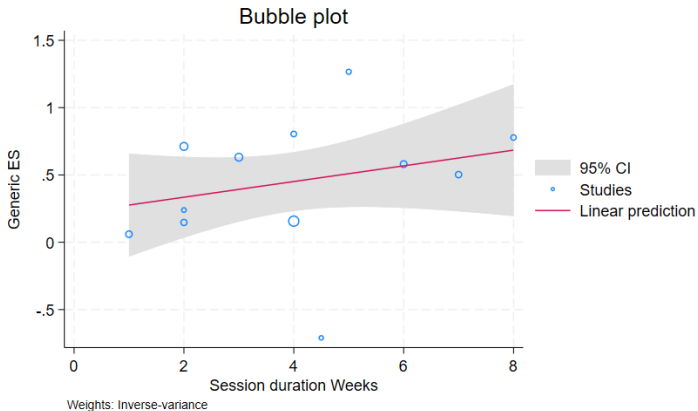
	_meta_es	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
SessiondurationWeeks		.0582585	.0547522	1.06	0.287	-.0490538	.1655708
_cons		.2180544	.2418207	0.90	0.367	-.2559055	.6920143

```
Test of residual homogeneity: Q_res = chi2(10) = 18.26 Prob > Q_res = 0.0508
```

```
estat bubbleplot
```

Postestimation: Bubble plot

```
. estat bubbleplot
```



Advanced Models in Meta-Analysis

Multivariate and Multilevel Meta-Analyses (Stata GUI)

The screenshot shows the 'meta - Meta-Analysis Control Panel' window. The 'Setup' tab is active. On the left, a vertical sidebar contains buttons for 'Setup', 'Summary', 'Forest plot', 'Heterogeneity', 'Regression', 'Publication bias', 'Multivariate', and 'Multilevel'. The 'Multivariate' button is highlighted. The main panel has tabs for 'Model', '#/in', 'Reporting', 'Maximization', and 'Postestimation'. The 'Model' tab is selected. A note states: 'Note: Multivariate meta-analysis ignores all meta settings.' Below this, the 'Multivariate meta-analysis' section includes a 'Dependent variables' dropdown, a checked 'Moderators' dropdown, and an unchecked 'Suppress constant term' checkbox. The 'Within-study variance-covariance information' section has two radio buttons: 'Specify variance and covariance variables in specific order' (selected) and 'Specify standard-error variables and correlations in specific order'. Below these are input fields for 'Standard-error variables' and 'Correlation values'. The 'Meta-analysis model' section has three radio buttons: 'Default model' (selected), 'Random effects', and 'Fixed effects'. An unchecked checkbox for 'Compute t tests for fixed-effects coefficients and specify degrees of freedom' is also present. At the bottom, status information shows 'No. of studies: 12', 'CI level: 95%', 'Model: Random effects', 'Method: REML', 'Effect size: es, Effect size Std. err.: se', and a 'Submit' button.

Multivariate Meta-Analysis
. meta mvregress

The screenshot shows the 'meta - Meta-Analysis Control Panel' window. The 'Setup' tab is active. On the left, a vertical sidebar contains buttons for 'Setup', 'Summary', 'Forest plot', 'Heterogeneity', 'Regression', 'Publication bias', 'Multivariate', and 'Multilevel'. The 'Multilevel' button is highlighted. The main panel has tabs for 'Model', '#/in', 'Reporting', 'EM options', 'Maximization', and 'Postestimation'. The 'Model' tab is selected. A note states: 'Note: Multilevel meta-analysis ignores all meta settings.' Below this, the 'Multilevel meta-regression' section has two radio buttons: 'Random-intercepts regression' (selected) and 'Mixed-effects regression'. The 'Fixed-effects model' section includes a 'Dependent variable' dropdown, an 'Independent variables' dropdown, and an unchecked 'Suppress constant term' checkbox. The 'Random-effects model' section has a 'Level variables' dropdown and an unchecked checkbox for 'Fix RE standard deviations to:'. The 'Effect-size sampling variability variable' section has two radio buttons: 'Standard errors' (selected) and 'Variances'. The 'Estimation method' section has two radio buttons: 'Restricted maximum likelihood (REML)' (selected) and 'Maximum likelihood'. A 'Constraints' dropdown and a 'Manage...' button are also present. At the bottom, status information shows 'No. of studies: 12', 'CI level: 95%', 'Model: Random effects', 'Method: REML', 'Effect size: es, Effect size Std. err.: se', and a 'Submit' button.

Multilevel Meta-Regression
. meta multilevel

Thank you!

dalarub@upo.es

References

- Botella, J. and Sánchez-Meca, J. (2015). *Meta-análisis en ciencias sociales y de la salud*. Síntesis, Madrid.
- Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods*, 11(2):364–386.
- Sterne, J. e. a. (2019). Rob 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*, 366:l4898. Published 28 August 2019.