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

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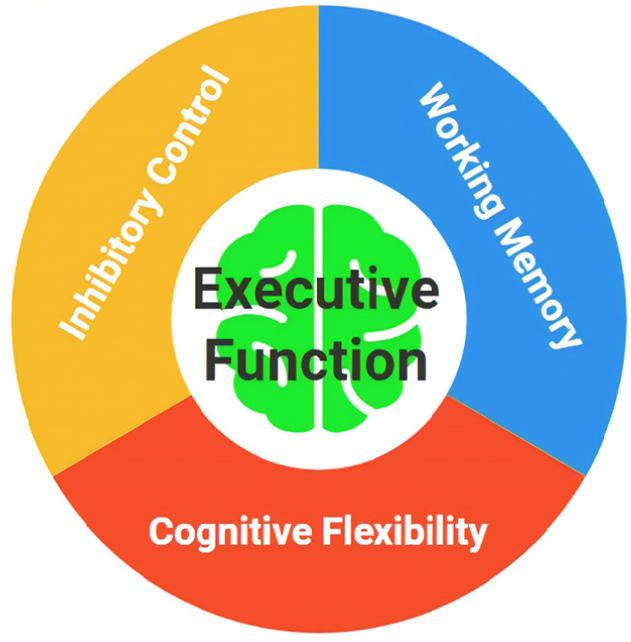
Outline

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)

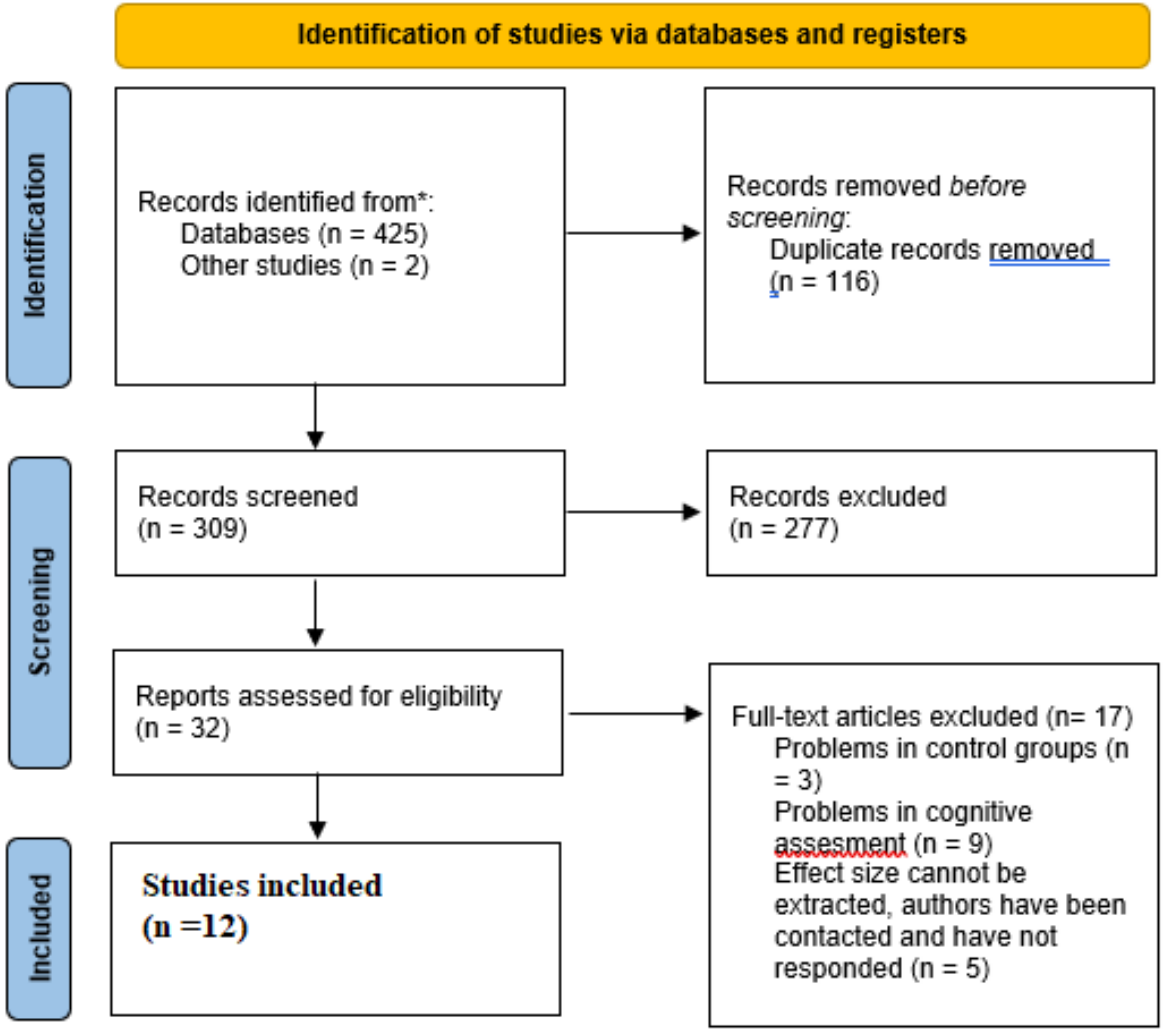


Figure: Flow diagram of study selection following PRISMA guidelines.

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):*

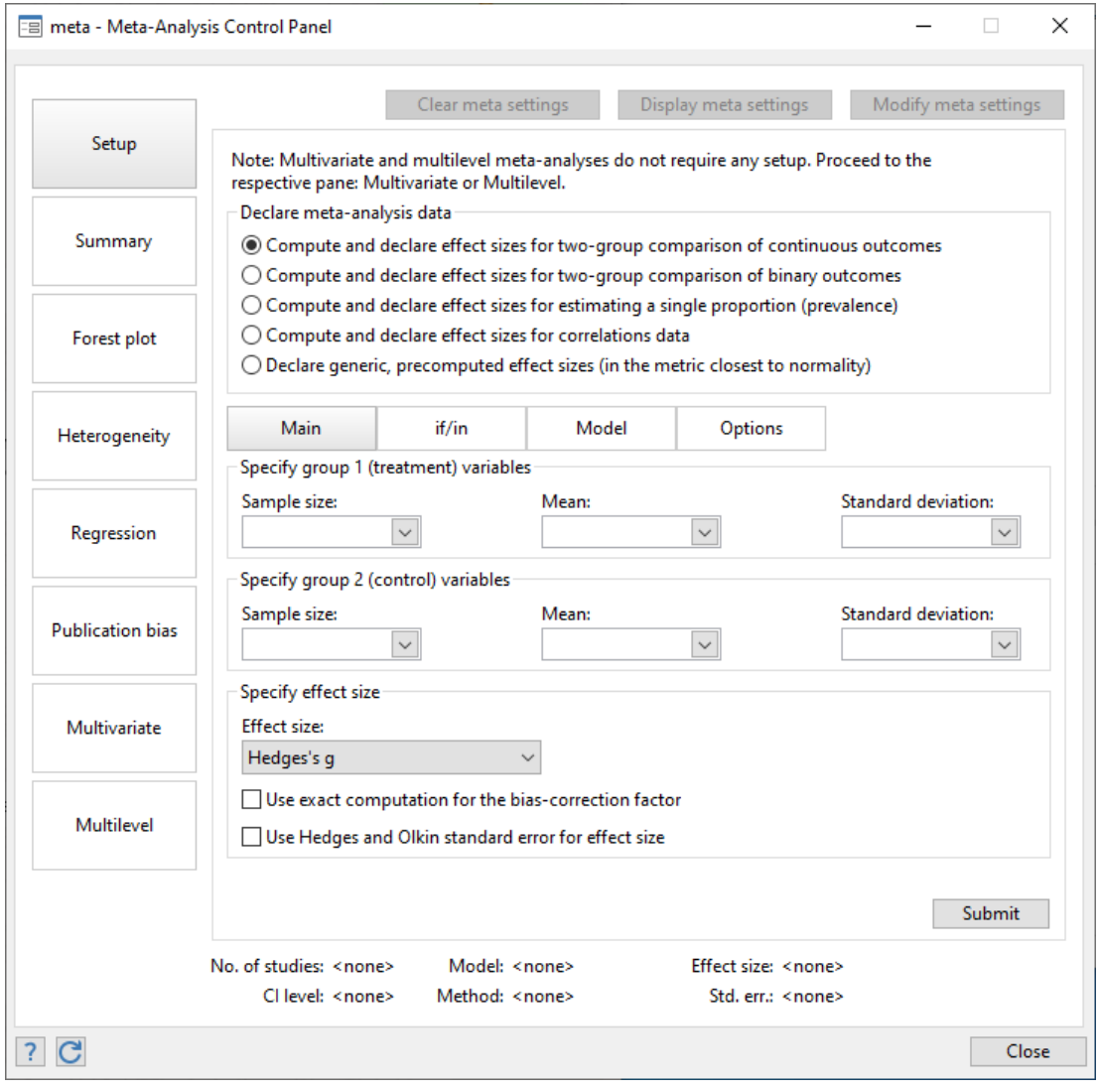
```
. meta esize nsucc ssize, esize(ftukeyprop)
```

- *Correlation data (Fisher's z):*

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

Source: Stata Meta-Analysis Overview

Meta-Analysis Setup in Stata GUI



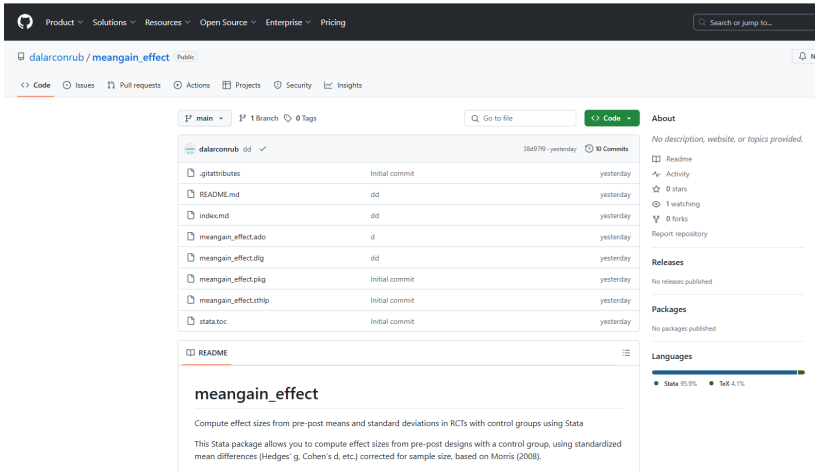
Graphical interface for specifying meta-analysis effect sizes and data structure in Stata.

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)`

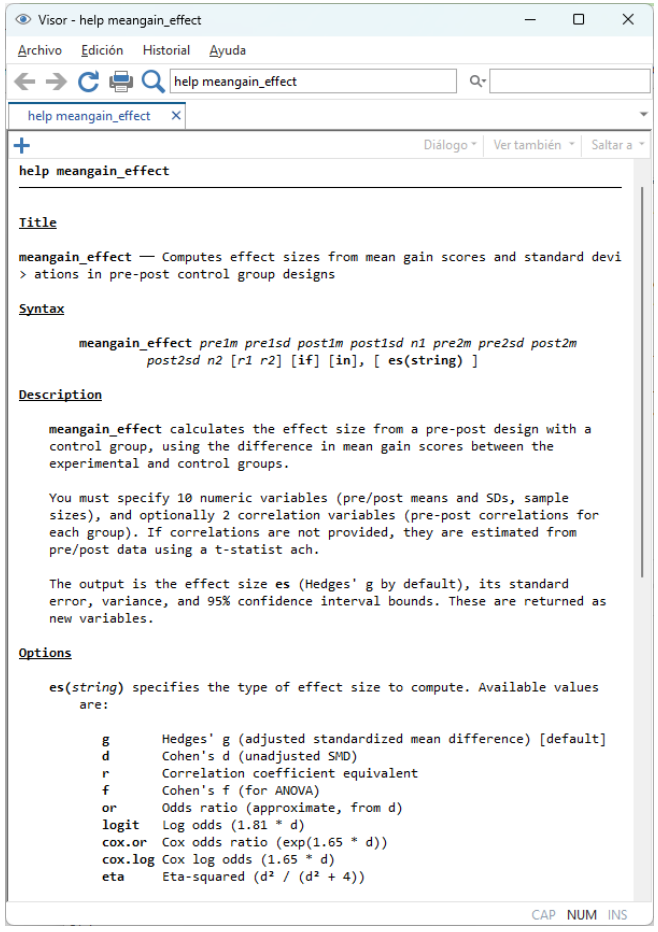
Compute Effect Size from Mean Gain Scores

User Package `meangain_effect`



Install from GitHub repository:

`dalarconrub/meangain_effect`

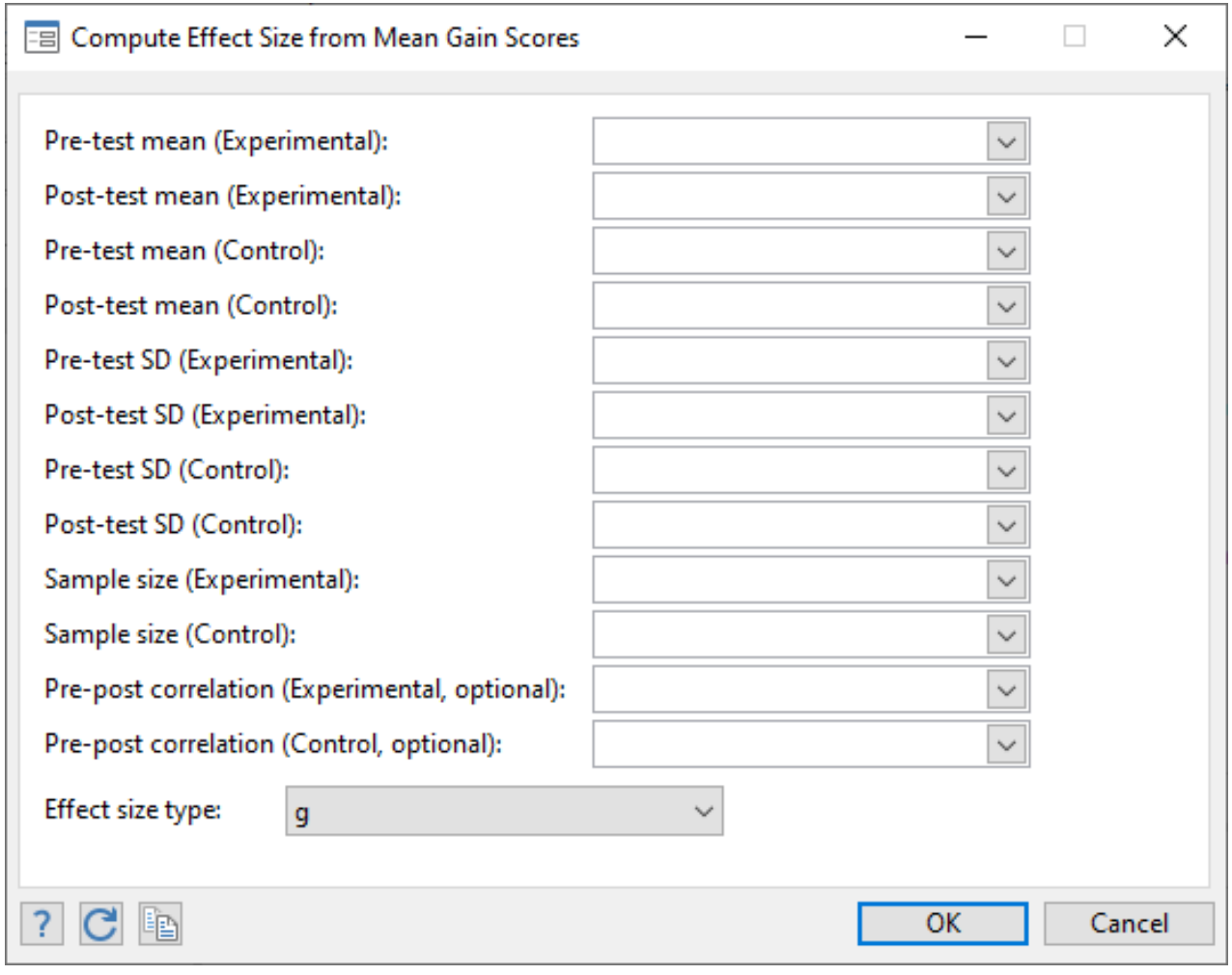


Help information:

```
. help meangain_effect
```

Compute Effect Size from Mean Gain Scores

```
. db meangain_effect
```



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                       Number of studies =     12
Random-effects model                        Heterogeneity:
Method: REML                                            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
```

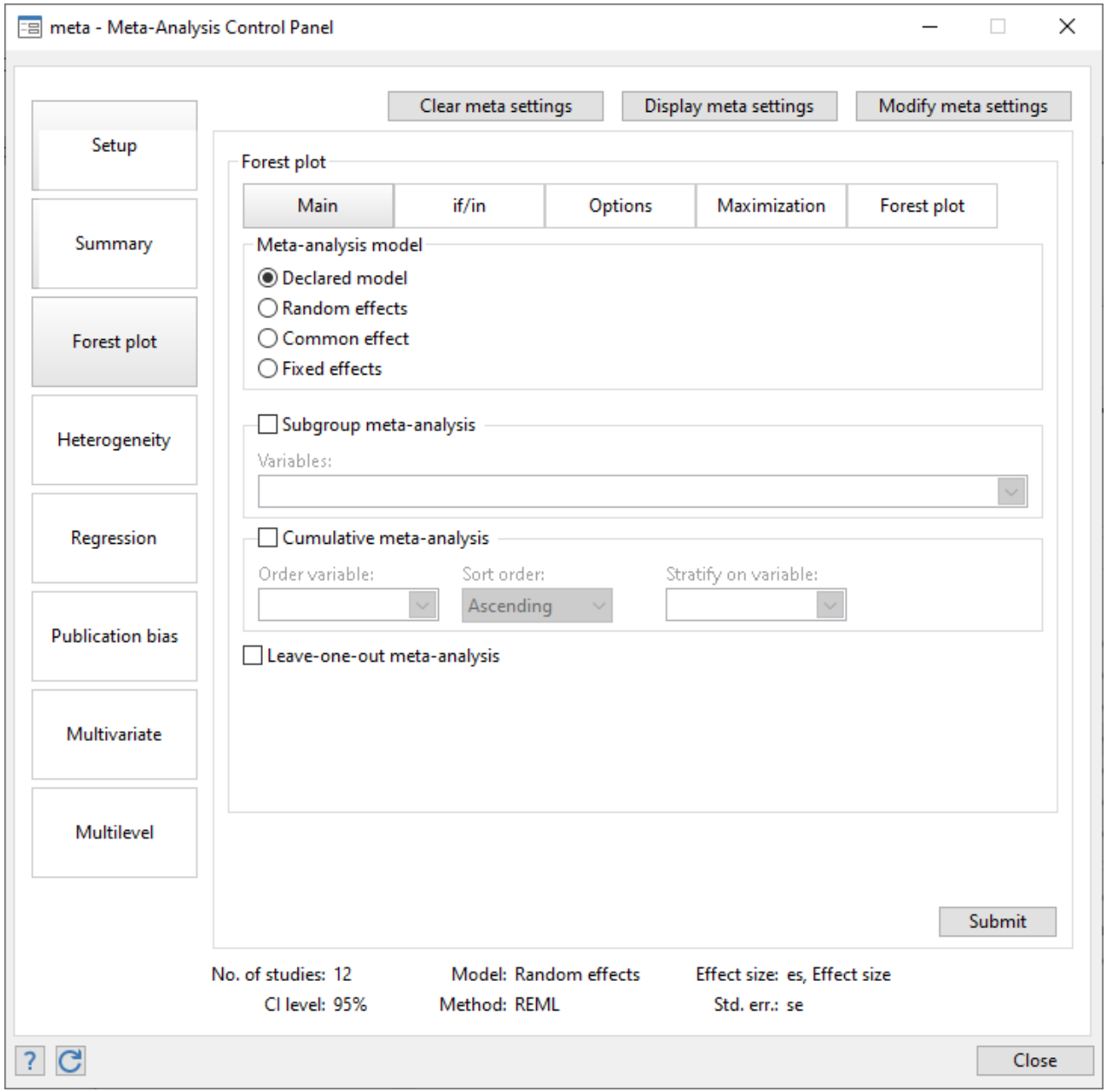
Overall Meta-Analytic Effect

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

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

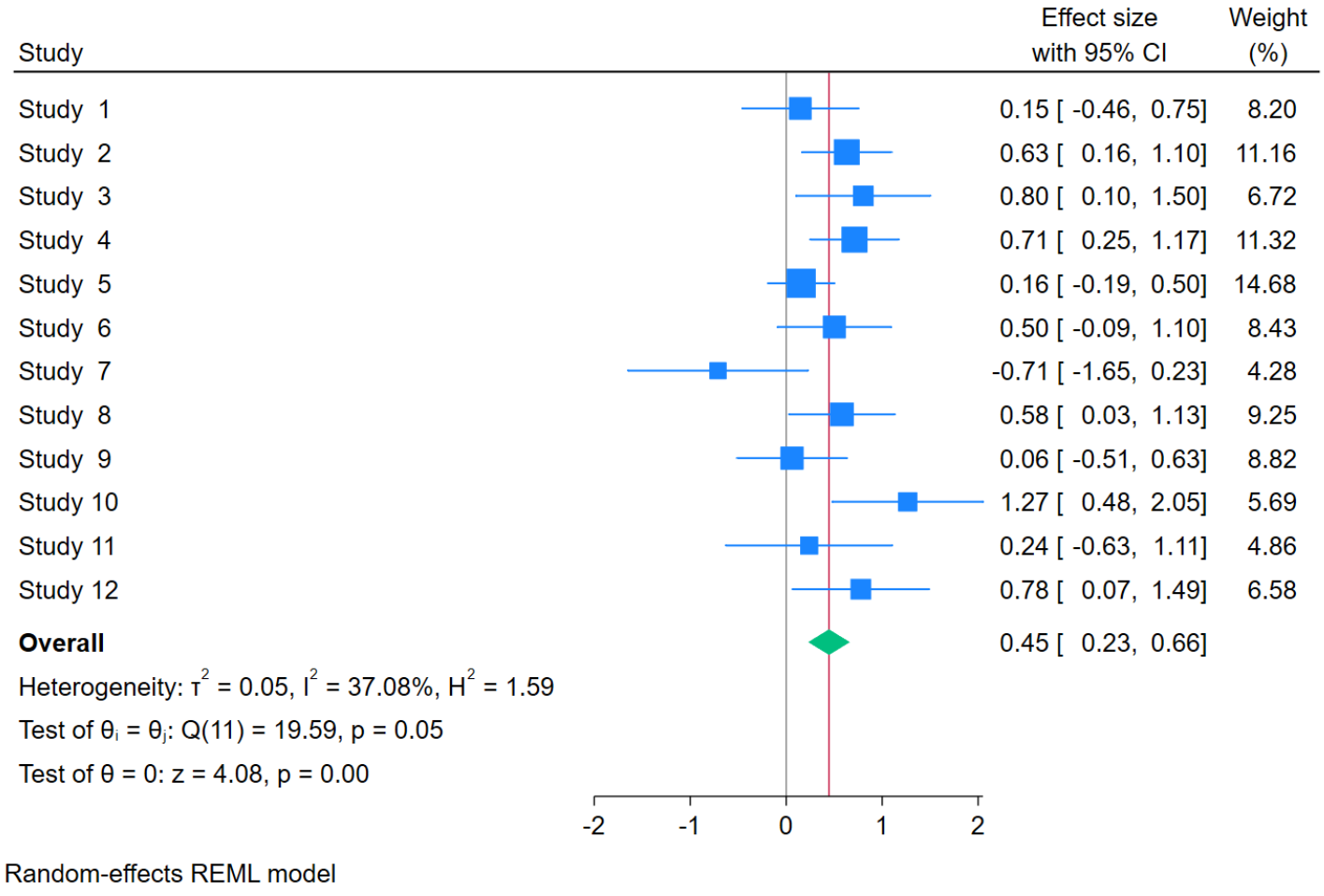
- Interpretation:
  - Moderate statistically significant effect
  - Suggests training improves cognitive performance
- Heterogeneity was low to moderate: $\tau^2 = 0.0505$, $I^2 = 37.08\%$, suggesting some variability across studies.
- The test for heterogeneity ($Q = 19.59$, $p = 0.051$) was marginally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

Forest Plot Dialog in Stata GUI



Forest Plot: Explore Heterogeneity

```
. meta forestplot
```

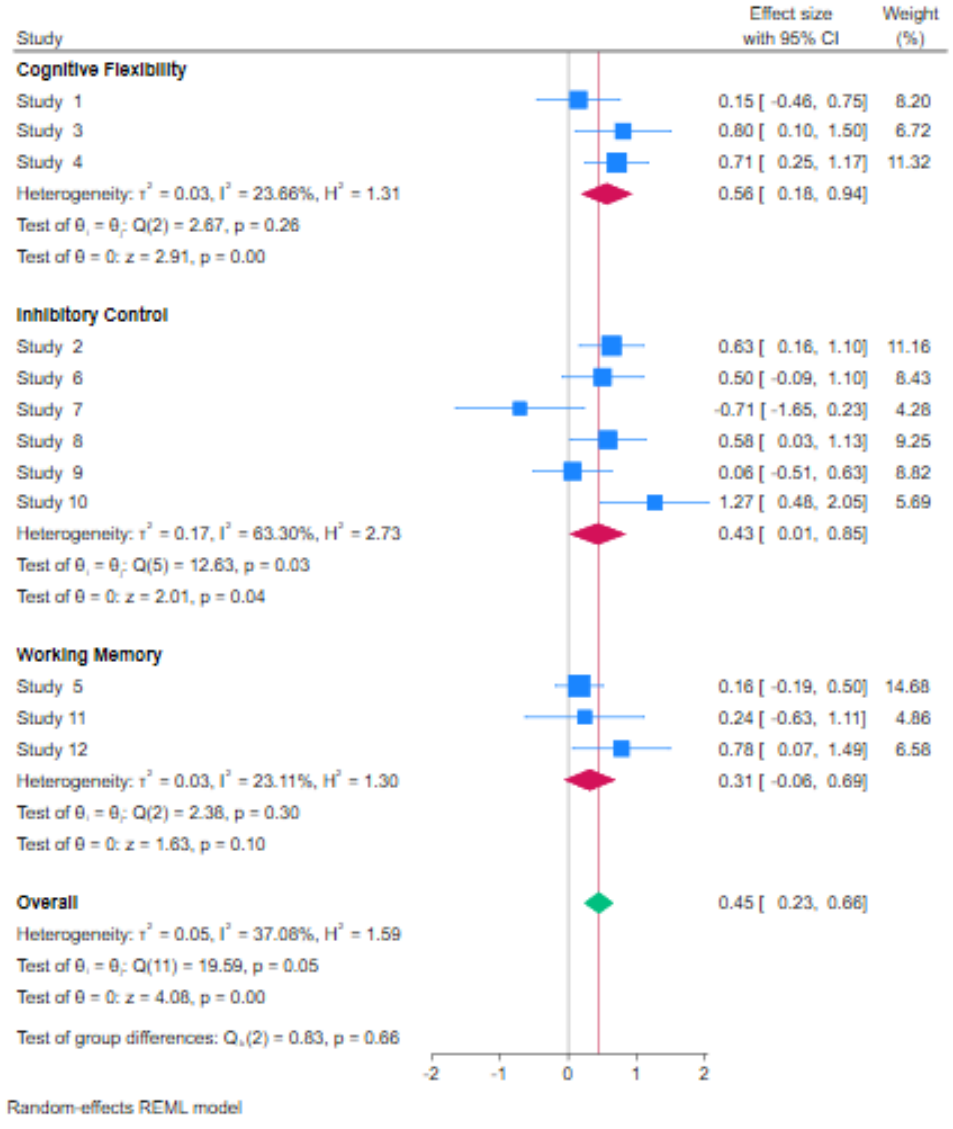


Subgroup Forest Plot by Outcome Task

- 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)
```



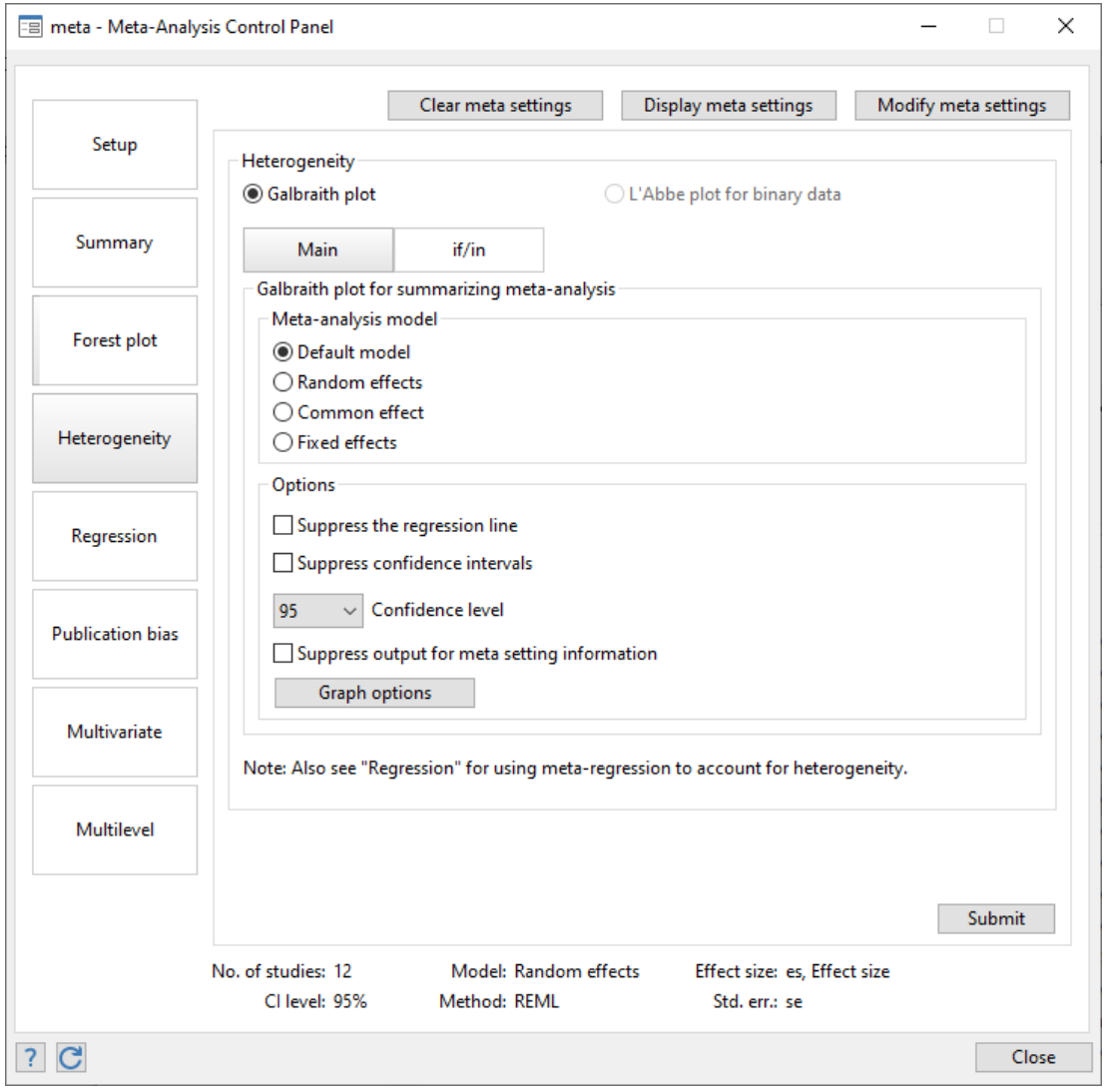
Subgroup Analysis Results

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.

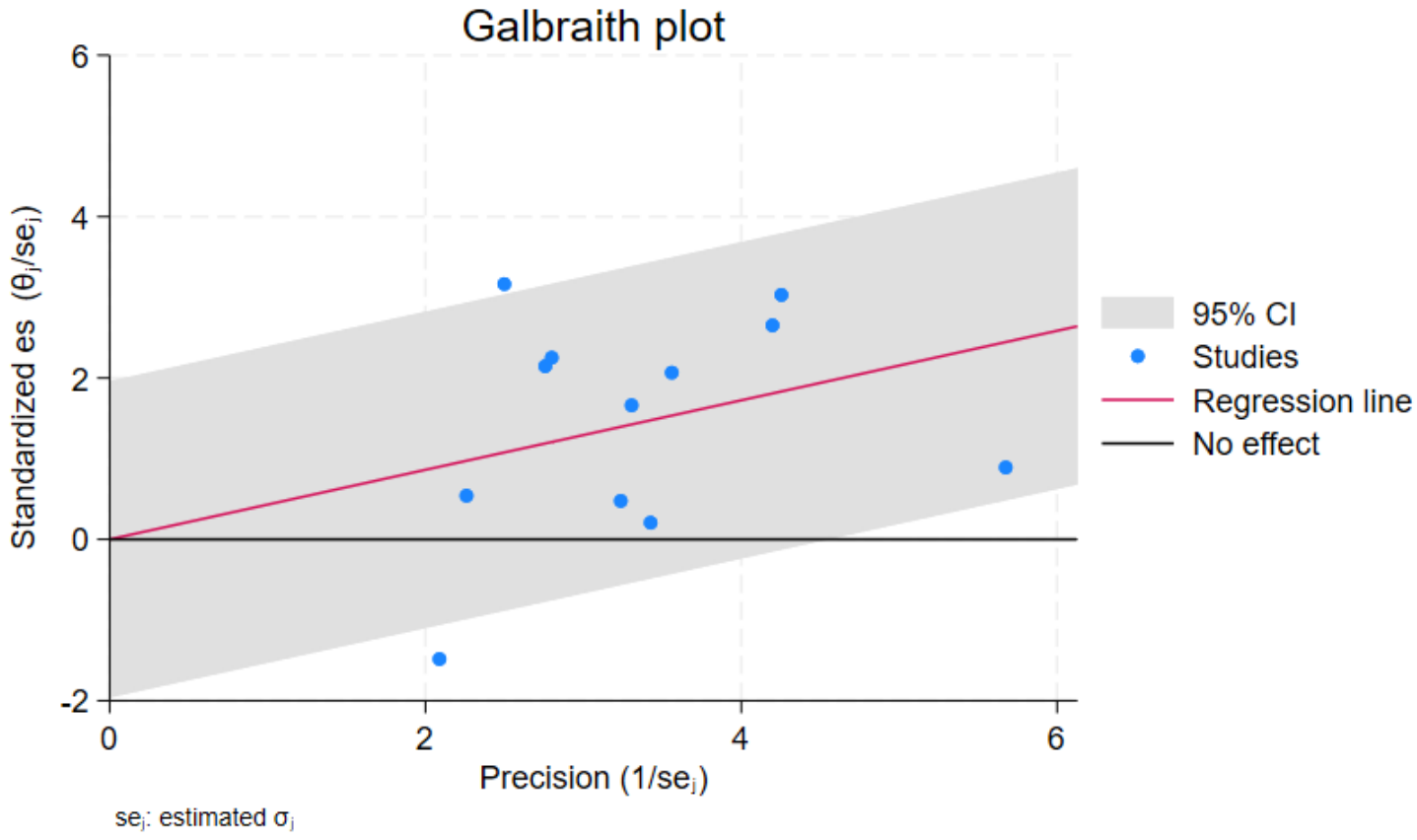
Galbraith plot for publication bias detection

Galbraith Plot Settings (Stata GUI)



Galbraith plot for publication bias detection

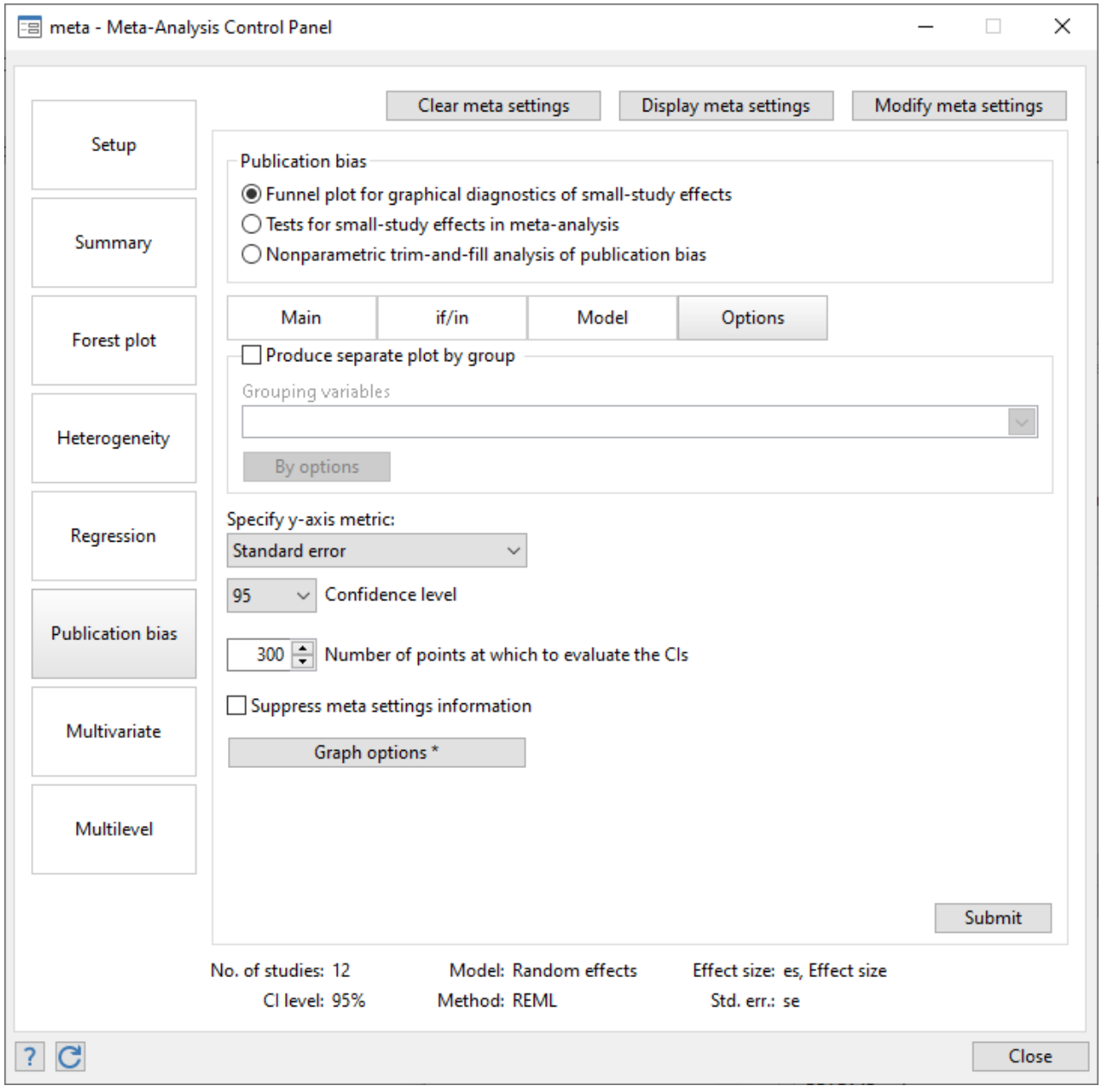
```
. meta galbraith
```



Galbraith plot for publication bias detection

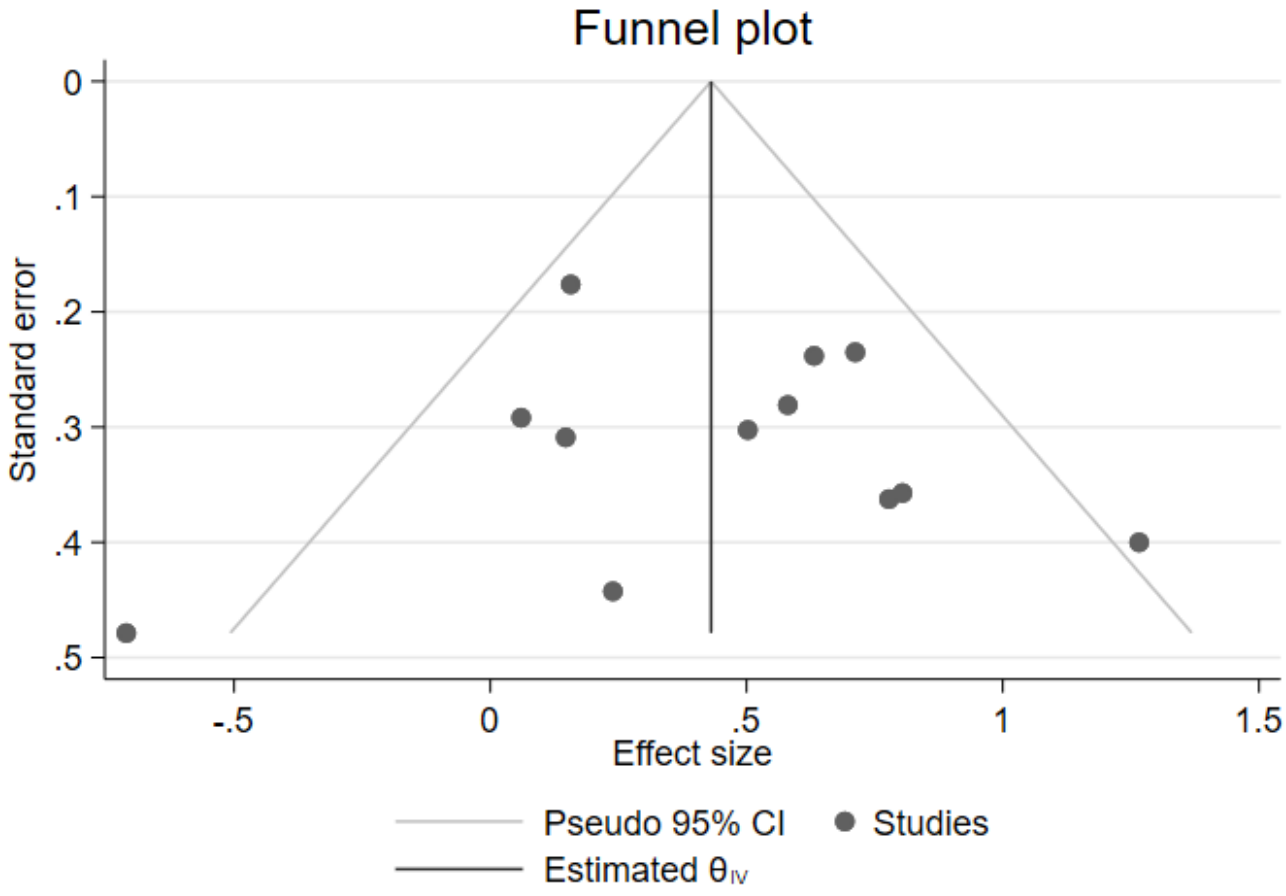
- The Galbraith plot displays standardized effect sizes (θ/SE_i) against precision ($1/\mathrm{SE}_i$).
- The shaded area shows the 95% confidence interval around the regression line.
- Most points fall within the expected bounds, suggesting no major publication bias or influential outliers.

Funnel Plot for Publication Bias (Stata GUI)



Funnel Plot for Publication Bias

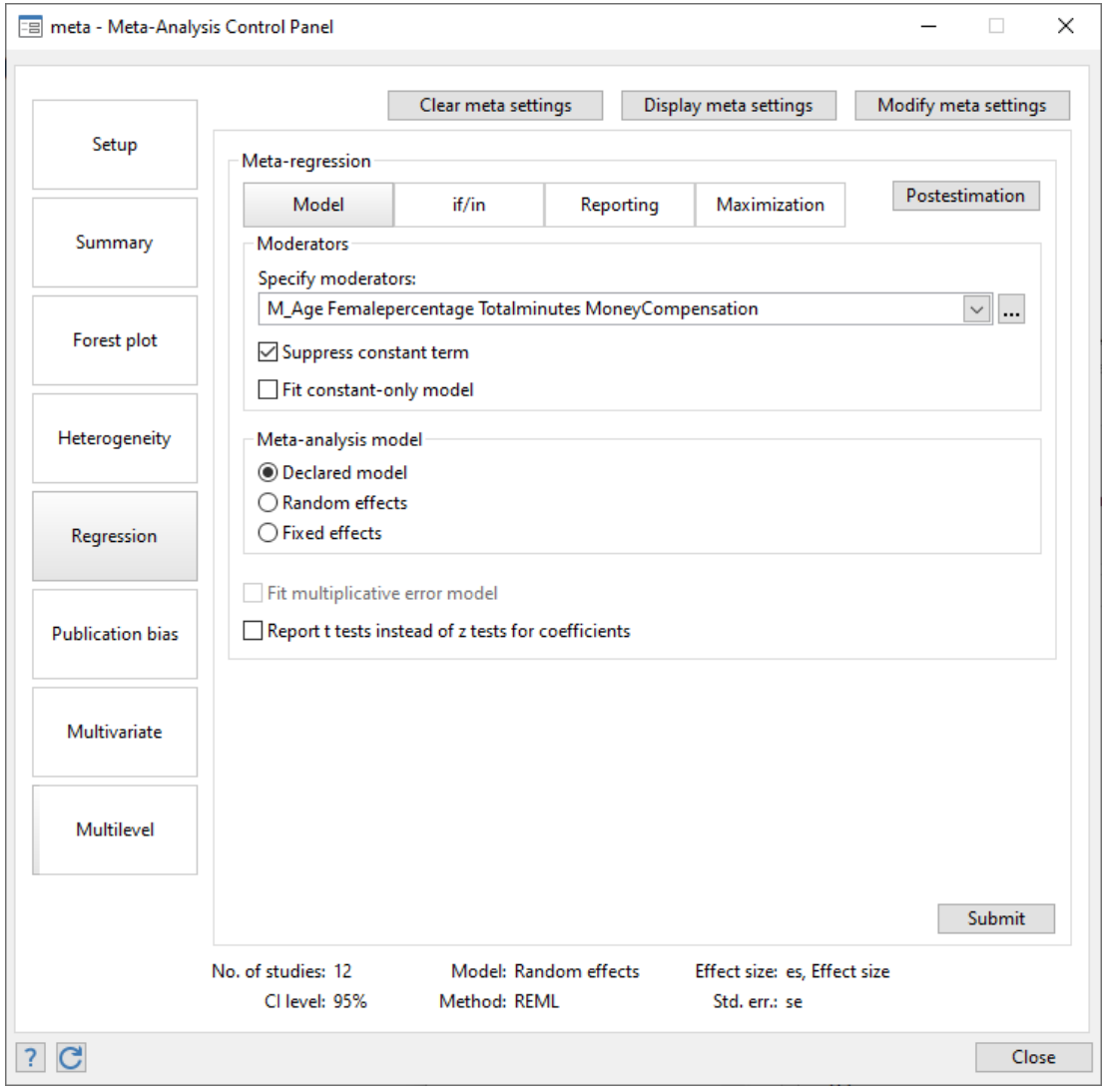
```
. meta funnelplot, scheme(stsj)
```



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 ($\hat{\theta}_{\text{IV}}$), 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-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                  Number of obs   =        12
Method: REML                                    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 ($Q_{\text{res}}(8) = 17.86$, $p = 0.0223$).

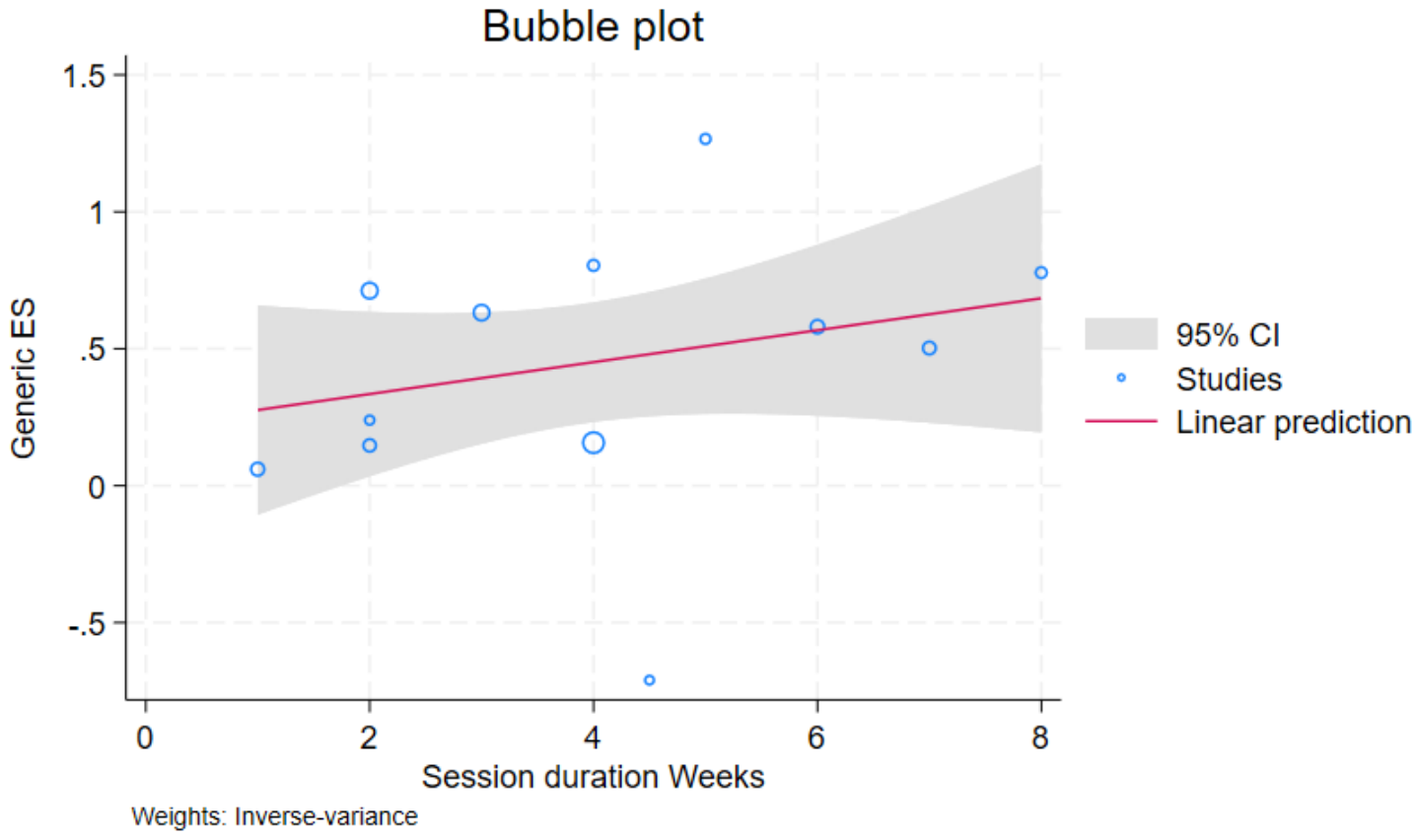
Postestimation: Bubble plot

Meta-regression with one continuous variable

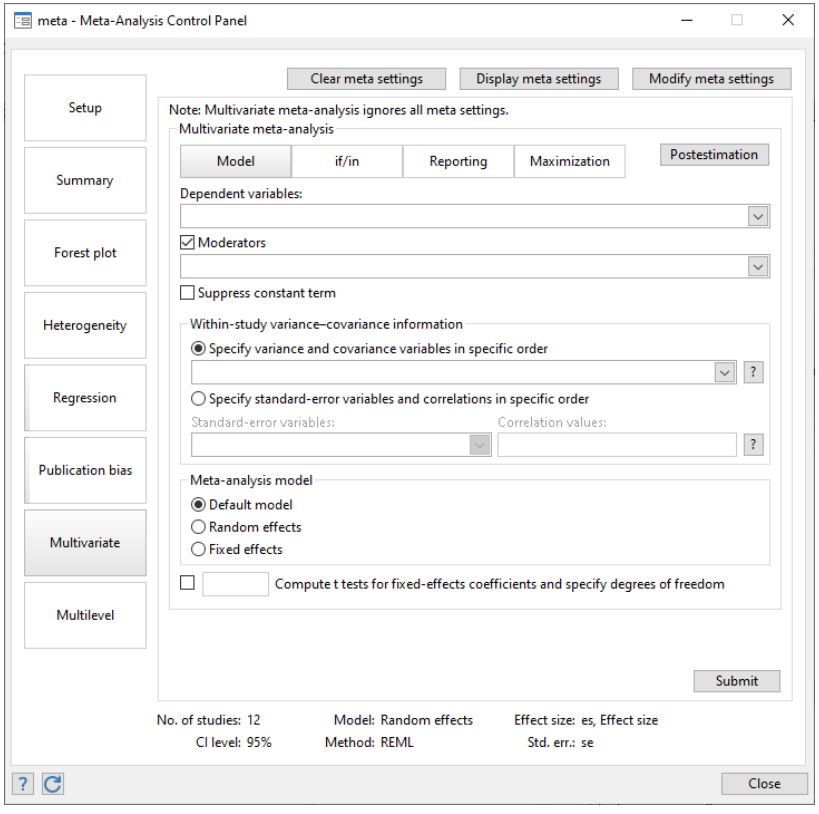
```
. meta regress SessiondurationWeeks

  Effect-size label: Effect size
        Effect size: es
          Std. err.: se

Random-effects meta-regression                  Number of obs  =        12
Method: REML                                    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
```

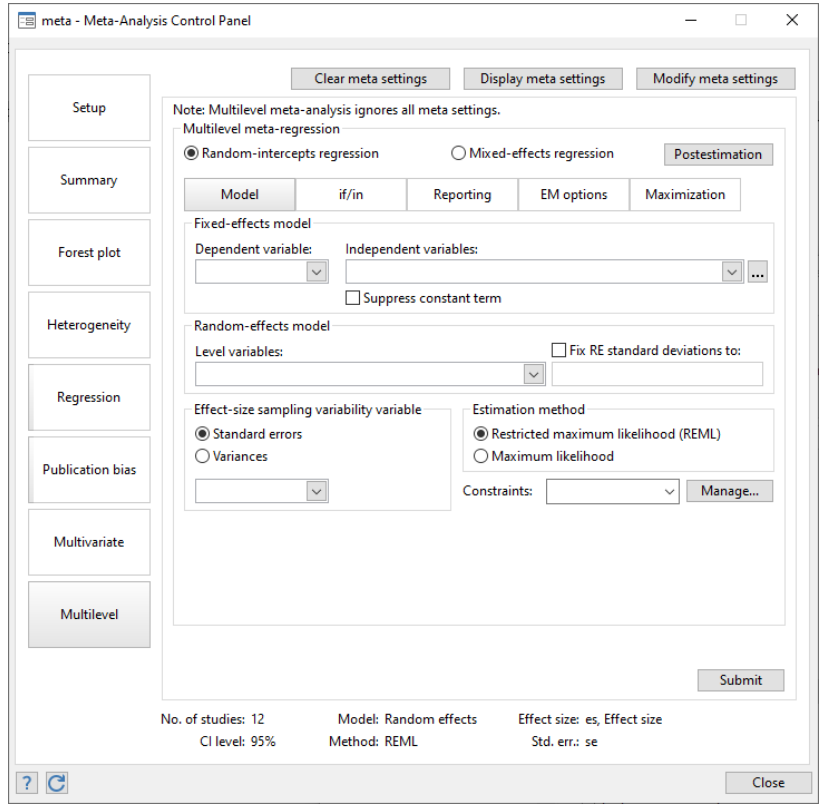


Advanced Models in Meta-Analysis
Multivariate and Multilevel Meta-Analyses (Stata GUI)



Multivariate Meta-Analysis

```
. meta mvregress
```



Multilevel Meta-Regression

```
. meta multilevel
```

Thank you!

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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.