

Power-enhanced funnel plots for meta-analysis: The sunset funnel plot

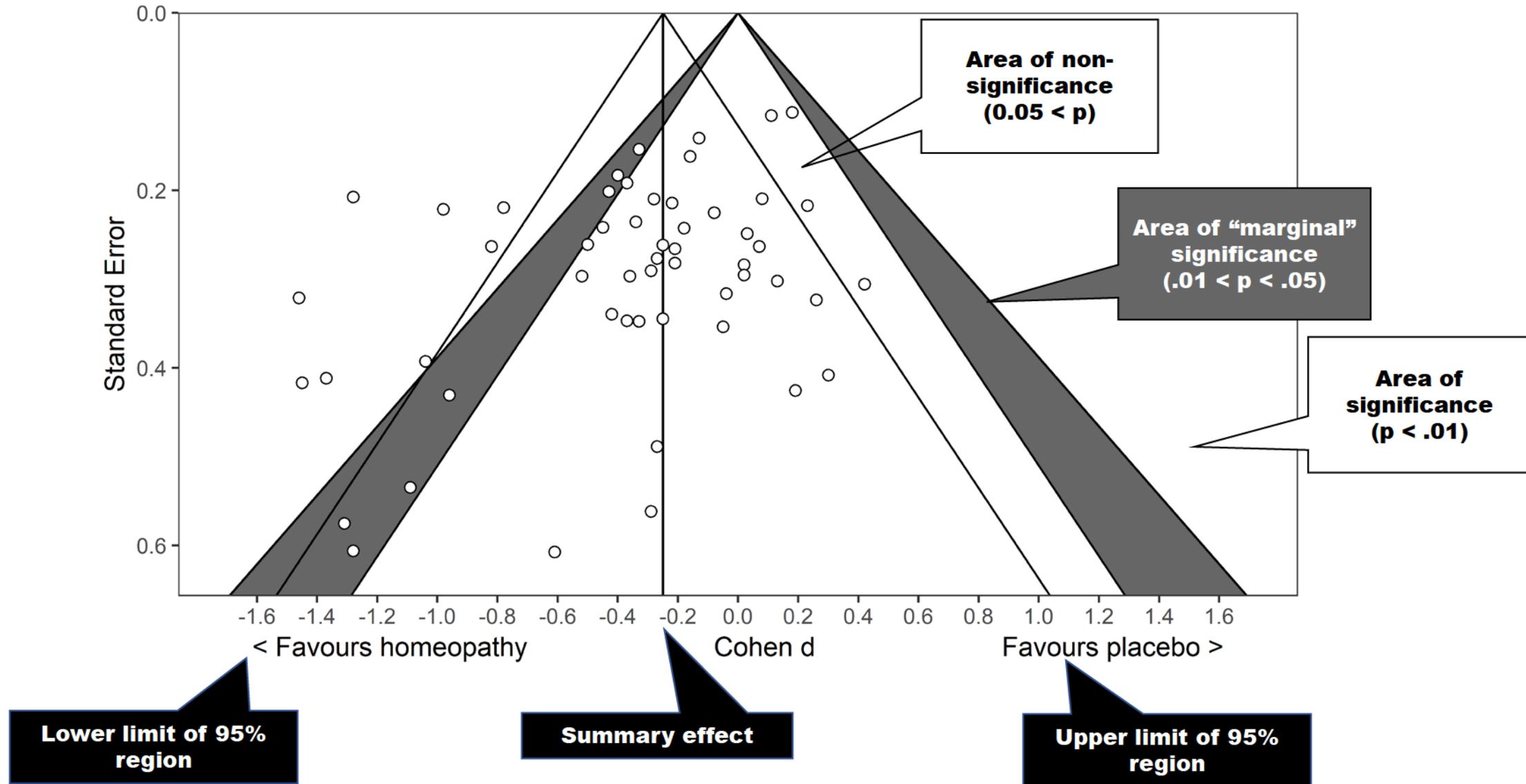
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The funnel plot



The funnel plot

- The funnel plot is the most widely used diagnostic plot for meta-analysis (Schild & Voracek, 2013)
- The funnel plot conveys a multitude of statistical information, e.g.:
 - Association of ES and SE (small-study effects)
 - Role of statistical significance
 - Study clusters, cross-study effect heterogeneity
 - Outliers, extreme values
- Several contour-enhanced variants of the funnel plot have been proposed
 - Significance contours (Peters, Sutton, Jones, Abrams, & Rushton, 2008)
 - Additional evidence contours
 - Effect heterogeneity statistics (Langan, Higgins, Gregory, & Sutton, 2012)
 - Significance of the summary effect (Langan, Higgins, Gregory, & Sutton, 2012)
 - Confidence interval width of the summary effect, and upper/lower limits (Crowther, Langan, & Sutton, 2012)
 - Magnitude of the summary effect (Chevance et al., 2015)

Study-level power – context & considerations

- Study-level power has been recognized as valuable for assessing the credibility and evidentiality of a set of findings in meta-analysis and meta-research
- The test of excess significance (TES) is an exploratory evidentiality test, based on the study-level power to detect an effect of interest (Ioannidis & Trikalinos, 2007)
 - More statistically significant studies than expected, considering their power, indicates bias
- Significant, but low-powered, findings more likely are false positives (Forstmeier, Wagenmakers, & Parker, 2017) and might be especially prone to result from questionable research practices (Muncer, Craigie, & Holmes, 2003)
- The deviation of (“gap between”) the proportion of observed significant studies and twice the median study power has been proposed as the R-Index of replicability (Schimmack, 2016)

The sunset funnel plot – rationale & intentions

- Currently, dedicated graphical displays to depict study-level statistical power in the context of meta-analysis are unavailable
- The sunset (i.e., power-enhanced) funnel plot directly incorporates study-level power into the well-known funnel plot display
 - Displays study-level power regions/contours
 - Has a second y axis (for power)
- Allows meta-analysts to incorporate power considerations into classic funnel plot assessments of small-study effects

The sunset funnel plot – assumptions

- For a (common) true population effect size δ , the power of a two-sided Wald test with significance level α testing the null hypothesis $\delta = 0$ is given by

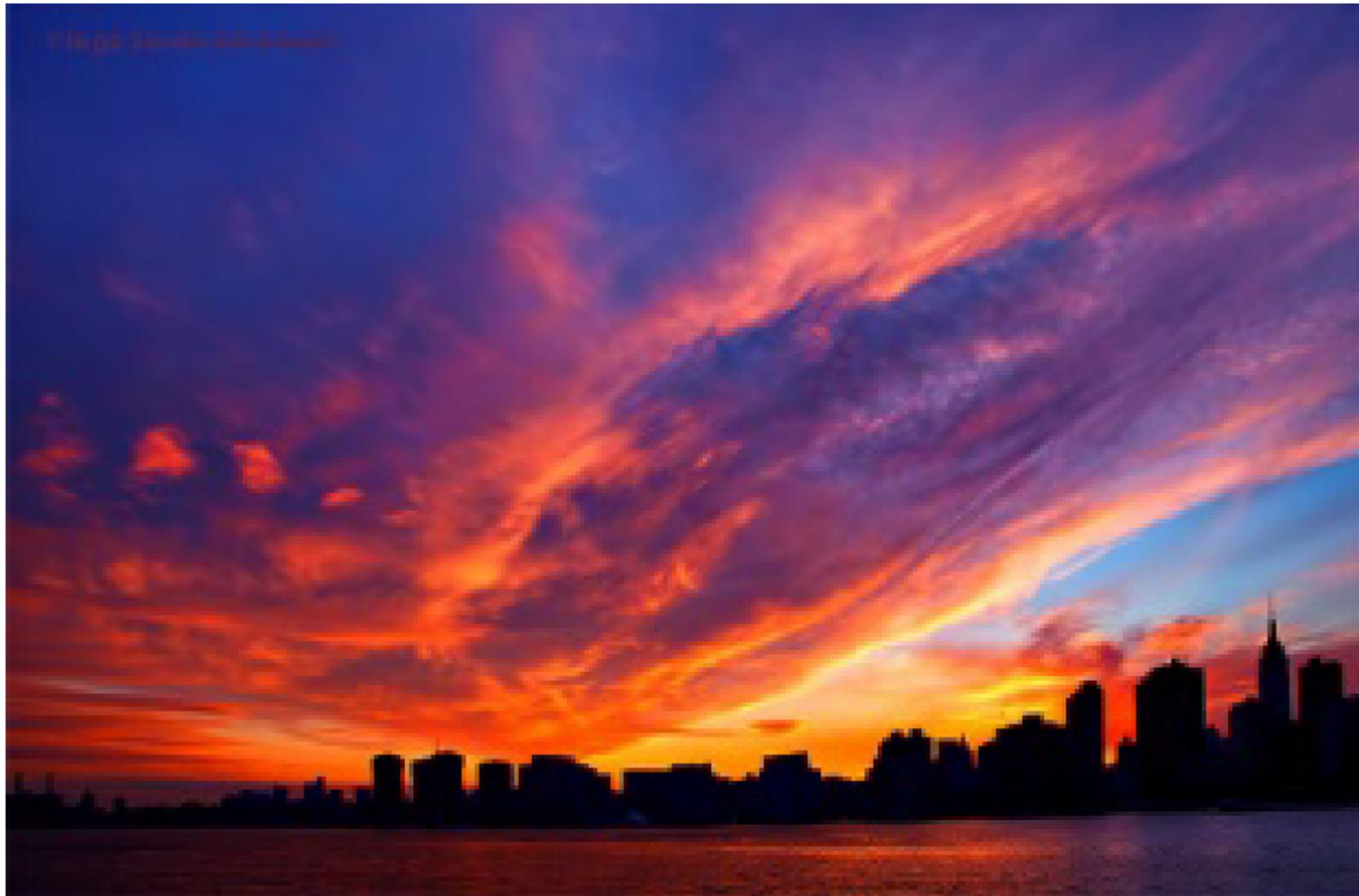
$$Power = 1 - \Phi\left(z_{1-\alpha/2} - \frac{\delta}{SE(d)}\right) + \Phi\left(-z_{1-\alpha/2} - \frac{\delta}{SE(d)}\right)$$

- Hence, for each standard error the corresponding power to detect an underlying effect of interest can be calculated
 - Assumptions: normally distributed effect sizes; and known variances (same as in the standard funnel plot)

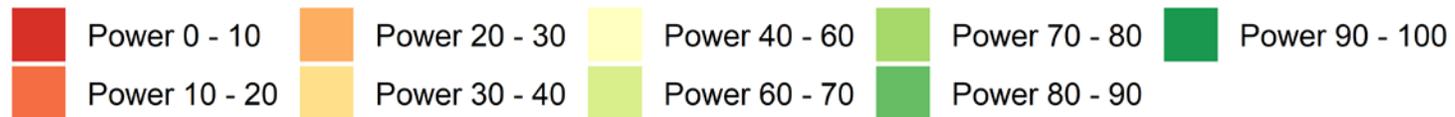
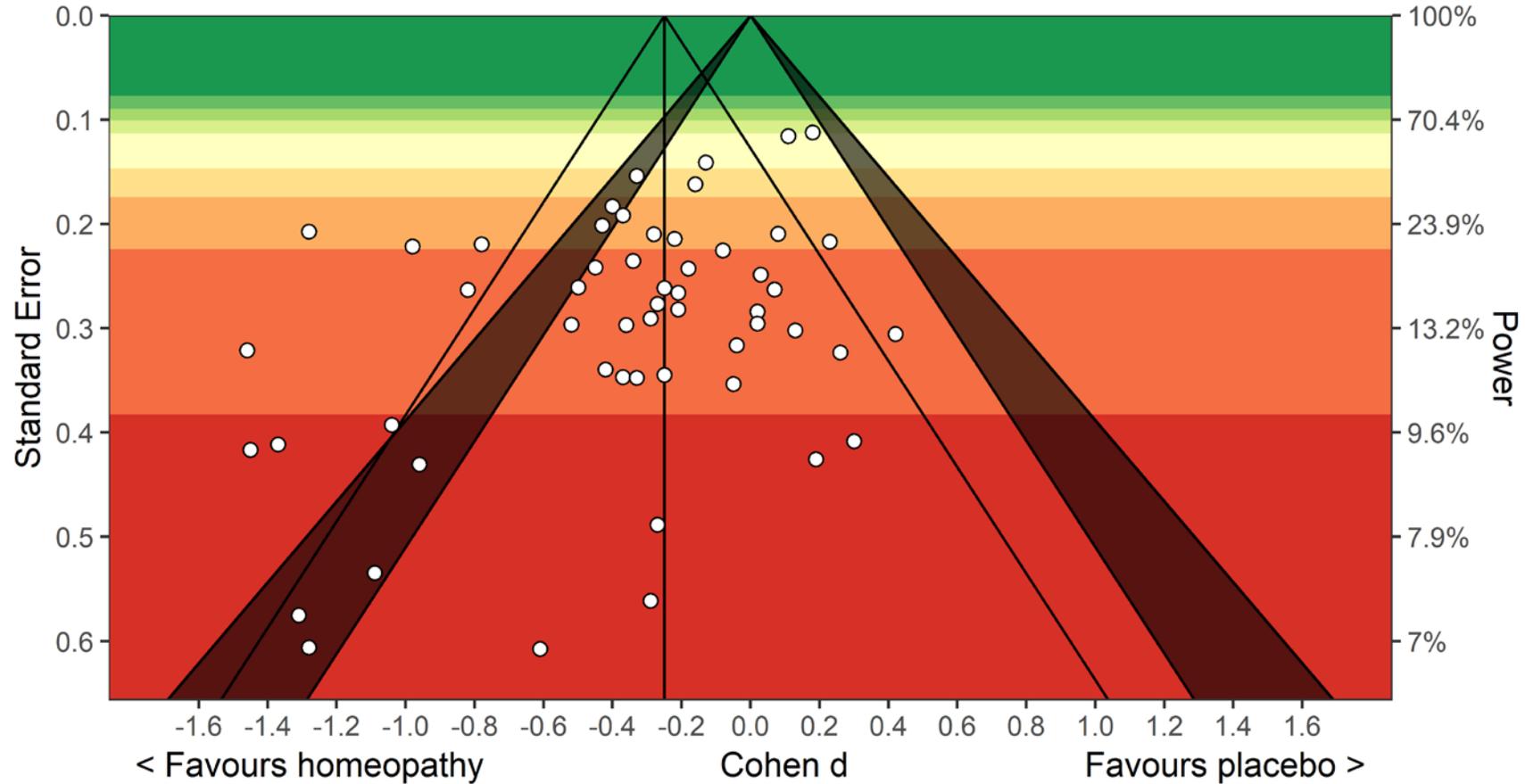
The sunset funnel plot – features & possibilities

- The underlying true population effect size can be...
 - Determined theoretically (e.g., by assuming a smallest effect of interest)
 - Estimated empirically, using meta-analytic estimates of the summary effect
- Related power-based statistics can be presented alongside the sunset (power-enhanced) funnel plot and support its evaluation
 - Median power of the set of studies
 - Necessary population effect size to reach certain levels of median power (e.g., 33% or 66%)
 - Results of the test of excess significance (Ioannidis & Trikalinos, 2007)
 - R-index, as a measure for the expected replicability of findings (Schimmack, 2016)

The sunset funnel plot – indeed

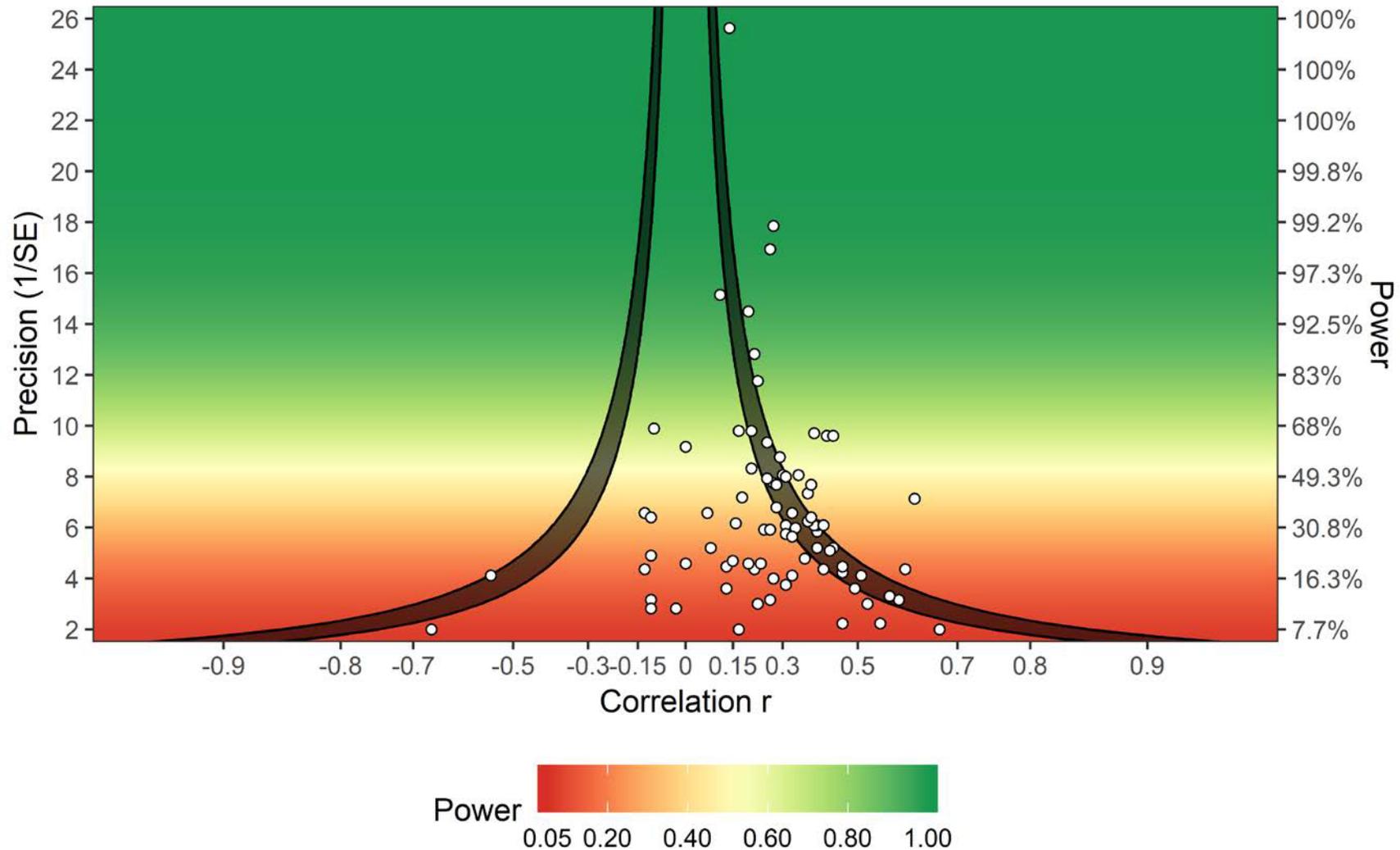


Example 1: Homeopathy



$\alpha = 0.05, \delta = -0.25 \mid \text{med}_{\text{power}} = 14.3\%, d_{33\%} = 0.43, d_{66\%} = 0.67 \mid E = 9.45, O = 15, p_{\text{TES}} = 0.047, R\text{-Index} = 0.8\%$

Example 2: Brain volume and intelligence



$\alpha = 0.05, \delta = 0.24$ | $\text{med}_{\text{power}} = 30.1\%$, $d_{33\%} = 0.26$, $d_{66\%} = 0.4$ | $E = 29.55$, $O = 41$, $p_{\text{TES}} = 0.009$, $R\text{-Index} = 10.8\%$

Sunset funnel plots with function `viz_sunset()` from R package **metaviz**

```
viz_sunset(x, y_axis = "se", true_effect = NULL, sig_level = 0.05,  
power_stats = TRUE, power_contours = "discrete", contours = FALSE,  
sig_contours = TRUE, text_size = 3, point_size = 2, xlab = "Effect", ylab =  
NULL, x_trans_function = NULL, x_breaks = NULL, y_breaks = NULL, x_limit =  
NULL, y_limit = NULL)
```

- Highly relevant for potential users: How can sunset funnel plots be created in practice?
- `viz_sunset()` within package **metaviz** is a tailored R function to plot sunset funnel plots and to compute power-related statistics
- Details and vignettes can be found at <https://CRAN.R-project.org/package=metaviz>

Shiny app demo: metaviz.shinyapps.io/sunset/



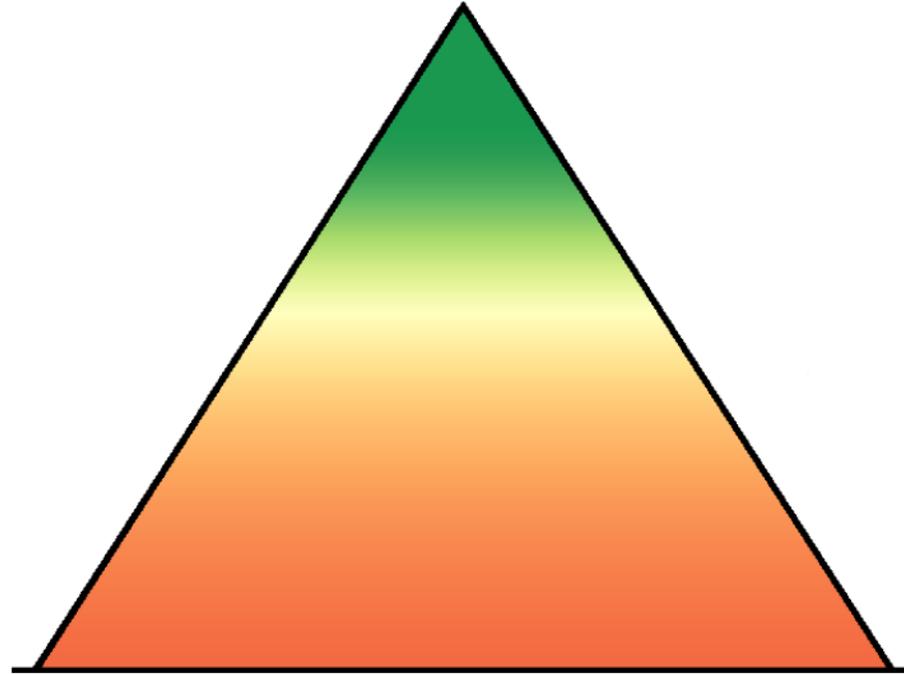
Summary & Conclusions (1)

- Study-level power is a potentially underused information in the context of meta-analysis
- Study-level power can be useful information for assessing the credibility and evidentiality of a set of empirical findings
 - An excess of significant findings might indicate bias
 - Nominally significant, but low-powered, studies might more likely be affected by questionable research practices
 - Insufficient power of nominally significant results decreases the likelihood of replicability
- The sunset funnel plot is the first dedicated graphical display for meta-analysis which directly incorporates study-level power for these purposes

Summary & Conclusions (2)

- The sunset plot is a novel, power-enhanced, variant of the well-known funnel plot
- For a set of studies, the sunset funnel plot allows graphically to ...
 - ...directly incorporate power considerations into classic funnel plot assessments of small-study effects
 - ...display the distribution and typical power levels for an underlying effect of interest
 - ...explore power levels for a set of studies for varying underlying effects of interest
- For meta-analysts, software to create sunset funnel plots is available as a tailored R function (alternatively, as a shiny app)

Thank you!



Questions?

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