

Package ‘ltgsmd’

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Title Latent True-Score and Target-Population Anchored Geometric SMD

Version 0.2.3

Description Implements the latent true-score and target-population anchored geometric standardized mean difference (LTG-SMD) framework for two-group effect-size analysis. Provides plug-in estimation, analytic delta-method confidence intervals using a sample fourth-moment plug-in, bias-corrected and bias-corrected-accelerated nonparametric bootstrap confidence intervals with study x group stratification, denominator-sensitivity profiles, and multi-site meta-analytic wrappers. Includes denominator-diagnostic reporting, a pluggable reliability estimator interface, and an explicit interface for specifying the target reference distribution. Companion software to Nakamura (2026) ``The Denominator Chooses the Estimand: A Target-Population True-Score Framework for Standardized Mean Differences" <[doi:10.1037/met0000875](https://doi.org/10.1037/met0000875)>.

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ltgsmd-package	<i>ltgsmd: Latent True-Score and Target-Population Anchored Geometric SMD</i>
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Description

Implements the LTG-SMD framework for two-group effect-size analysis. The LTG-SMD is a standardized mean difference whose denominator is the geometric mean of group-specific true-score standard deviations in an explicitly chosen target reference population. The package supports single-study analyses with internal holdout references, analyses with external norm samples, and multi-site coordinated-replication analyses with cross-site pooled references.

Core functions

- `compute_ltg_smd()` Compute the LTG-SMD and four conventional comparators (Hedges’s g, Welch-type SMD, observed geometric SMD, external observed SMD) from study and reference data.
- `ltg_smd_ci()` Analytic delta-method and bias-corrected (BC) or BCa nonparametric bootstrap confidence intervals.
- `denominator_diagnostics()` Table F.1 diagnostics for reporting (Section 8.3 of the paper).
- `denominator_sensitivity()` Profile across six symmetric denominators (Simulation D; Section 5.3 of the paper).
- `sensitivity_reference()` Sensitivity to the choice of target reference.
- `multisite_ltg_smd()` Multi-site analysis with cross-site pooled reference and meta-analytic comparison.
- `export_supplementary()` Bundle diagnostics, CIs, and sensitivity profiles for a supplementary appendix.

Companion paper

Nakamura, D. (2026). The denominator chooses the estimand: A target-population true-score framework for standardized mean differences. *Psychological Methods*. Advance online publication. doi:10.1037/met0000875

Run `citation("ltgsmd")` for this reference in text and BibTeX form. See the package vignette `vignette("getting-started", package = "ltgsmd")` for worked examples corresponding to Sections 6.1, 6.2, and 6.3 of the paper.

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See Also

Useful links:

- [doi:10.17605/OSF.IO/KW9R6](https://doi.org/10.17605/OSF.IO/KW9R6)

coef_alpha

Compute coefficient alpha (Cronbach's alpha)

Description

Computes Cronbach's coefficient alpha from item-level data. Uses listwise-complete cases by default. The implementation follows the standard formula

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum_i s_i^2}{s_T^2} \right)$$

where k is the number of items, s_i^2 are item variances, and s_T^2 is the variance of the total score.

Usage

```
coef_alpha(items, na.rm = TRUE)
```

Arguments

<code>items</code>	A data frame, matrix, or list-like object whose columns are item-level responses (one row per respondent).
<code>na.rm</code>	Logical. If TRUE (default), use complete cases only.

Value

A numeric scalar, the value of coefficient alpha.

Examples

```
set.seed(1)
items <- matrix(rnorm(400), ncol = 4)
coef_alpha(items)
```

compute_ltg_smd

Compute the LTG-SMD and related effect-size estimates

Description

Computes the latent true-score and target-population anchored geometric standardized mean difference (LTG-SMD) along with conventional comparators: Hedges's g , Welch-type SMD, observed geometric SMD (within study), and external observed geometric SMD (in the reference sample).

Usage

```
compute_ltg_smd(
  study_data,
  reference_data,
  group_var,
  score_var = NULL,
  items = NULL,
  group_levels = NULL,
  reliability_estimator = "alpha",
  rho_external = NULL,
  se_method = c("fourth_moment", "normal"),
  verbose = FALSE
)
```

Arguments

<code>study_data</code>	A data frame containing the study sample, with one row per participant.
<code>reference_data</code>	A data frame containing the reference sample. May be the same as <code>study_data</code> if an internal (holdout) reference is used; see Section 8.2 of the paper.
<code>group_var</code>	Character. Name of the grouping variable in both data frames.
<code>score_var</code>	Character. Name of the precomputed composite score variable. If <code>NULL</code> , the composite is built by averaging the items in <code>items</code> .
<code>items</code>	Optional character vector of item names. Required if <code>score_var</code> is <code>NULL</code> , or if reliability is to be estimated from item-level data.
<code>group_levels</code>	Named character vector with names "reference" (group 0) and "focal" (group 1) specifying the levels of <code>group_var</code> . If <code>NULL</code> , the two unique values are sorted alphabetically with the first taken as reference.
<code>reliability_estimator</code>	Either the string "alpha" (default; uses <code>coef_alpha()</code>) or a function taking a matrix/data frame of items and returning a numeric scalar in (0, 1]. Custom estimators allow plugging in <code>psych::omega()</code> , CFA-based reliability, or any user-supplied procedure.

rho_external	Optional named numeric vector with names "focal" and "reference" specifying externally supplied reliability estimates. If provided, these override the internal estimator. Each value must lie in (0, 1].
se_method	Character. "fourth_moment" (default; uses sample fourth moments as described in Section 4.2 and Supplementary Section C of the paper) or "normal" (uses the simpler $2\sigma^4/(m-1)$ approximation that is valid under normality).
verbose	Logical. If TRUE, prints intermediate quantities.

Details

The LTG-SMD estimand (Section 2.3 of the companion paper) is

$$\delta_{\text{LTG}} = \frac{\mu_{T1} - \mu_{T0}}{(\sigma_{T1,R}^2 \sigma_{T0,R}^2)^{1/4}}$$

where μ_{Tg} are true-score means and $\sigma_{Tg,R}^2$ are group-specific true-score variances in the target reference population R . The plug-in estimator substitutes observed study-sample means for the true-score means (assuming $\mu_{Yg} = \mu_{Tg}$) and reference-sample reliabilities times reference-sample observed variances for the true-score variances.

Hedges's small-sample correction factor $J(N) = 1 - 3/(4N - 9)$ is applied to the conventional Hedges's g estimate but not to the LTG-SMD or to the observed geometric SMDs, consistent with conventional practice.

The analytic SE under `se_method = "fourth_moment"` uses $\widehat{\text{Var}}(s^2) = (\hat{\mu}_4 - \frac{m-3}{m-1}(s^2)^2)/m$, which is consistent under arbitrary distributions of the score with finite fourth moments and reduces to the normal-theory approximation $2\sigma^4/(m-1)$ when the score is normal. Reliability is treated as fixed at its point estimate (the reliability-fixed approximation of Section 4.2); a reliability-propagated alternative is implemented by the bootstrap in `ltg_smd_ci()`.

Value

An object of class "ltg_smd" containing:

point Numeric. The LTG-SMD point estimate.

se_analytic Numeric. The analytic delta-method standard error (reliability-fixed approximation; see Section 4.2).

se_method Character. Which SE method was used.

estimates Numeric vector with elements `hedges_g`, `welch_smd`, `observed_geometric`, `external_observed`, `ltg_smd`.

study Data frame of group-level study-sample statistics.

reference Data frame of group-level reference-sample statistics.

c_g Numeric vector of length 2: study-to-reference SD ratios (`c_focal`, `c_reference`).

rho_g Numeric vector of length 2: reliability estimates (`rho_focal`, `rho_reference`) in the reference sample.

factors Named numeric vector with `reliability_factor`, `study_to_target_factor`, `predicted_ratio_observed_to_LTG`.

call The matched call.

Examples

```

set.seed(2026)
gen_items <- function(n, shift = 0) {
  true <- rnorm(n)
  data.frame(
    item1 = true + rnorm(n, sd = 0.6) + shift,
    item2 = true + rnorm(n, sd = 0.6) + shift,
    item3 = true + rnorm(n, sd = 0.6) + shift,
    item4 = true + rnorm(n, sd = 0.6) + shift
  )
}
study_df <- rbind(
  cbind(condition = "control", gen_items(15)),
  cbind(condition = "treatment", gen_items(15, shift = 0.5))
)
reference_df <- rbind(
  cbind(condition = "control", gen_items(30)),
  cbind(condition = "treatment", gen_items(30, shift = 0.5))
)

result <- compute_ltg_smd(
  study_data = study_df,
  reference_data = reference_df,
  group_var = "condition",
  items = c("item1", "item2", "item3", "item4"),
  group_levels = c(reference = "control", focal = "treatment")
)
print(result)

# Custom reliability estimator: use psych::omega instead of alpha
# (illustrated on a larger synthetic sample, since omega needs more
# data than alpha to fit stably)
if (requireNamespace("psych", quietly = TRUE)) {
  gen_items6 <- function(n, shift = 0) {
    true <- rnorm(n)
    items <- as.data.frame(replicate(6, true + rnorm(n, sd = 0.6),
                                          simplify = FALSE))

    names(items) <- paste0("item", 1:6)
    items[] <- lapply(items, `+`, shift)
    items
  }
  study_big <- rbind(
    cbind(condition = "control", gen_items6(60)),
    cbind(condition = "treatment", gen_items6(60, shift = 0.5))
  )
  reference_big <- rbind(
    cbind(condition = "control", gen_items6(100)),
    cbind(condition = "treatment", gen_items6(100, shift = 0.5))
  )
  my_omega <- function(items) psych::omega(items, plot = FALSE)$omega.tot
  result_omega <- compute_ltg_smd(
    study_big, reference_big,

```

```

    group_var = "condition",
    items = paste0("item", 1:6),
    reliability_estimator = my_omega,
    group_levels = c(reference = "control", focal = "treatment")
  )
  print(result_omega)
}

```

denominator_diagnostics

Denominator diagnostics for an LTG-SMD analysis

Description

Produces the diagnostic table recommended in Section 8.3 of the companion paper (Table F.1 format). The table reports group-level sample sizes, observed standard deviations, reference reliabilities, true-score standard deviations, study-to-reference ratios c_g , Hedges's g , the LTG-SMD, the reliability factor $(\rho_1 \rho_0)^{1/4}$, the study-to-target factor $(c_1 c_0)^{-1/2}$, the predicted ratio of the within-study observed geometric SMD to the LTG-SMD (exact under the decomposition), and the observed ratio of Hedges's g to the LTG-SMD (which approximately matches the predicted ratio with small deviations due to the pooled-versus-geometric denominator and Hedges's J correction).

Usage

```
denominator_diagnostics(x)
```

Arguments

`x` An "ltg_smd" object.

Value

A data frame in a long format suitable for direct reporting. The data frame has class "denominator_diagnostics".

Examples

```

set.seed(2026)
gen_items <- function(n, shift = 0) {
  true <- rnorm(n)
  data.frame(
    item1 = true + rnorm(n, sd = 0.6) + shift,
    item2 = true + rnorm(n, sd = 0.6) + shift,
    item3 = true + rnorm(n, sd = 0.6) + shift,
    item4 = true + rnorm(n, sd = 0.6) + shift
  )
}
study_df <- rbind(
  cbind(condition = "control", gen_items(15)),

```

```

  cbind(condition = "treatment", gen_items(15, shift = 0.5))
)
reference_df <- rbind(
  cbind(condition = "control", gen_items(30)),
  cbind(condition = "treatment", gen_items(30, shift = 0.5))
)
result <- compute_ltg_smd(study_df, reference_df,
  group_var = "condition", items = c("item1", "item2", "item3", "item4"),
  group_levels = c(reference = "control", focal = "treatment"))
diag <- denominator_diagnostics(result)
print(diag)

```

denominator_sensitivity

Denominator-sensitivity profile across six symmetric denominators

Description

Computes the LTG-SMD estimate under each of six symmetric denominator rules applied to the group-specific reference-sample true-score standard deviations: geometric (default), arithmetic, harmonic, root mean square, minimum, and maximum. This profile mirrors the six symmetric denominators compared in Simulation D (Section 5.3 of the companion paper; Supplementary Section D.4) and is recommended as supplementary material (Supplementary Section F.2.4), particularly when group-specific reference true-score variances differ markedly.

Usage

```
denominator_sensitivity(x)
```

Arguments

`x` An "ltg_smd" object.

Value

A data frame with one row per denominator rule, columns denominator, D, estimate. Class "denominator_sensitivity".

Examples

```

set.seed(2026)
gen_items <- function(n, shift = 0) {
  true <- rnorm(n)
  data.frame(
    item1 = true + rnorm(n, sd = 0.6) + shift,
    item2 = true + rnorm(n, sd = 0.6) + shift,
    item3 = true + rnorm(n, sd = 0.6) + shift,
    item4 = true + rnorm(n, sd = 0.6) + shift
  )
}

```

```

}
study_df <- rbind(
  cbind(condition = "control", gen_items(15)),
  cbind(condition = "treatment", gen_items(15, shift = 0.5))
)
reference_df <- rbind(
  cbind(condition = "control", gen_items(30)),
  cbind(condition = "treatment", gen_items(30, shift = 0.5))
)
result <- compute_ltg_smd(study_df, reference_df,
  group_var = "condition", items = c("item1", "item2", "item3", "item4"),
  group_levels = c(reference = "control", focal = "treatment"))
sens <- denominator_sensitivity(result)
print(sens)

```

export_supplementary *Export an LTG-SMD analysis to a supplementary appendix template*

Description

Bundles the point estimates, confidence intervals, denominator diagnostics, and denominator-sensitivity profile into a list and (optionally) writes them to a Markdown file for inclusion in a supplementary appendix.

Usage

```
export_supplementary(object, ci = NULL, file = NULL)
```

Arguments

object	An "ltg_smd" object.
ci	An optional "ltg_smd_ci" object from <code>ltg_smd_ci()</code> .
file	Optional path. If supplied, the supplementary appendix is written there as Markdown. If NULL, only the list is returned.

Value

Invisibly, a list with elements diagnostics, sensitivity, estimates, and ci. If file is supplied, the Markdown is also written to disk.

ltg_smd_ci

*Compute confidence intervals for the LTG-SMD***Description**

Computes one or more confidence intervals for the LTG-SMD, including the analytic delta-method interval (reliability-fixed; Section 4.2 of the paper) and the bias-corrected (BC) or bias-corrected-and-accelerated (BCa) nonparametric bootstrap interval.

Usage

```
ltg_smd_ci(
  object,
  method = c("analytic", "bootstrap"),
  boot_type = c("bc", "bca", "percentile"),
  B = 2000,
  level = 0.95,
  seed = NULL,
  parallel = c("no", "multicore", "snow"),
  ncpus = 1L,
  study_data = NULL,
  reference_data = NULL,
  group_var = NULL,
  score_var = NULL,
  items = NULL,
  group_levels = NULL,
  reliability_estimator = "alpha",
  rho_external = NULL
)
```

Arguments

object	An object of class "ltg_smd" returned by <code>compute_ltg_smd()</code> .
method	Character vector with elements from <code>c("analytic", "bootstrap")</code> . Both can be requested.
boot_type	Character. Type of bootstrap interval: "bc" (bias-corrected, default), "bca" (bias-corrected and accelerated), or "percentile" (uncorrected percentile interval).
B	Integer. Number of bootstrap replicates. Default 2000.
level	Numeric. Confidence level, default 0.95.
seed	Optional integer for reproducibility of the bootstrap.
parallel	Character; passed to <code>boot::boot()</code> . Default "no".
ncpus	Integer; passed to <code>boot::boot()</code> if <code>parallel != "no"</code> .
study_data	Data frame. Required for bootstrap (the original study sample passed to <code>compute_ltg_smd()</code>).

reference_data Data frame. Required for bootstrap.
 group_var, score_var, items, group_levels, reliability_estimator
 Same as in `compute_ltg_smd()`; required when bootstrap is requested.
 rho_external Optional; see `compute_ltg_smd()`.

Details

Stratification. The bootstrap resamples within the four strata defined by the cross-classification of source (study vs reference) and experimental group (focal vs reference). This preserves the sample sizes of all four study x group cells across replicates, which is the appropriate stratification for a two-group LTG-SMD analysis. Earlier versions of this package stratified only on source; that design allowed the group-1/group-0 ratio within each source to vary across replicates, producing unstable confidence intervals under small samples or unequal group sizes.

Reliability propagation. Because the bootstrap recomputes the entire LTG-SMD plug-in within each replicate, item-level reliability is re-estimated each time (when `items` is supplied). This propagates uncertainty in the reliability estimator through to the interval. By contrast, the analytic interval treats reliability as fixed at its point estimate.

Value

An object of class "ltg_smd_ci" containing:

analytic Named numeric vector with elements estimate, lower, upper, se, level.

bootstrap Named numeric vector with bootstrap interval, or NULL if bootstrap not requested.

boot_details If bootstrap requested, list with B, type, seed, z0, acceleration, strata_design, and the bootstrap distribution.

Examples

```
set.seed(2026)
gen_items <- function(n, shift = 0) {
  true <- rnorm(n)
  data.frame(
    item1 = true + rnorm(n, sd = 0.6) + shift,
    item2 = true + rnorm(n, sd = 0.6) + shift,
    item3 = true + rnorm(n, sd = 0.6) + shift,
    item4 = true + rnorm(n, sd = 0.6) + shift
  )
}
study_df <- rbind(
  cbind(condition = "control", gen_items(15)),
  cbind(condition = "treatment", gen_items(15, shift = 0.5))
)
reference_df <- rbind(
  cbind(condition = "control", gen_items(30)),
  cbind(condition = "treatment", gen_items(30, shift = 0.5))
)
result <- compute_ltg_smd(study_df, reference_df,
  group_var = "condition", items = c("item1", "item2", "item3", "item4"),
  group_levels = c(reference = "control", focal = "treatment"))
```

```
# B is kept small here so the example runs quickly; in practice use a
# larger B (e.g. 2000, the default) for stable bootstrap intervals.
ci <- ltg_smd_ci(result,
  method = c("analytic", "bootstrap"),
  B = 200, seed = 20260814,
  study_data = study_df, reference_data = reference_df,
  group_var = "condition", items = c("item1", "item2", "item3", "item4"),
  group_levels = c(reference = "control", focal = "treatment"))
print(ci)
```

multisite_ltg_smd

Multi-site LTG-SMD analysis with cross-site reference anchoring

Description

Implements the multi-site workflow described in Section 7.3 and illustrated in Example 3 (Section 6.3) of the paper (Many Labs 2 Anderson.1). Each site is treated as a study sample, the cross-site pooled distribution (or an external sample) is treated as the target reference, and site-level Hedges's g and LTG-SMD estimates are returned along with a meta-analytic comparison from `metafor::rma()`.

Usage

```
multisite_ltg_smd(
  data,
  site_var,
  group_var,
  score_var = NULL,
  items = NULL,
  group_levels = NULL,
  reliability_estimator = "alpha",
  reference_strategy = c("pooled_across_sites", "external"),
  reference_data = NULL,
  min_n_per_group = 50L,
  rho_external = NULL
)
```

Arguments

<code>data</code>	A data frame with one row per participant containing group, site, item-level, and (optionally) composite-score columns.
<code>site_var</code>	Character. Name of the site grouping variable.
<code>group_var</code>	Character. Name of the experimental-condition variable.
<code>score_var</code>	Optional character. Name of a precomputed composite score column. If NULL, built from <code>items</code> (in both data and, if supplied, <code>reference_data</code>).
<code>items</code>	Optional character vector of item column names.

<code>group_levels</code>	Optional named character vector with names "reference" and "focal".
<code>reliability_estimator</code>	Either "alpha" (default) or a function; see compute_ltg_smd() .
<code>reference_strategy</code>	One of "pooled_across_sites" (default; uses all retained sites as the reference) or "external" (requires <code>reference_data</code>).
<code>reference_data</code>	Optional data frame; required when <code>reference_strategy = "external"</code> .
<code>min_n_per_group</code>	Integer. Minimum per-group sample size for a site to be retained. Defaults to 50.
<code>rho_external</code>	Optional named numeric vector with names "focal" and "reference" to override item-level reliability estimation.

Details

The site-level standard error for the LTG-SMD is approximated as

$$\widehat{SE}_{\text{LTG,site}} = \sqrt{s_{1,\text{site}}^2/n_{1,\text{site}} + s_{0,\text{site}}^2/n_{0,\text{site}} / D},$$

treating the cross-site (or external) reference denominator D as fixed. This approximation is reasonable when the reference sample is large relative to each site, which is typical in coordinated multi-site projects, but it understates uncertainty when the reference is small. For a full reliability-propagated interval at the site level, use [ltg_smd_ci\(\)](#) with `method = "bootstrap"` on each site separately.

Value

An object of class "multisite_ltg_smd" containing:

- site_table** Data frame of site-level estimates: `site`, `n_focal`, `n_reference`, `hedges_g`, `ltg_smd`, `se_hedges`, `se_ltg`.
- reference_summary** List of pooled reference quantities (variances, reliabilities, true-score geometric SD).
- meta_hedges** Output of [metafor::rma\(\)](#) for Hedges's g .
- meta_ltg** Output of [metafor::rma\(\)](#) for the LTG-SMD.
- meta_comparison** Data frame summarizing the two meta-analytic pools side by side.
- se_ltg_method** Character. Notes that the site-level SE for the LTG-SMD treats the reference denominator as fixed.

Examples

```
set.seed(2026)
gen_site <- function(site_name, n_per_cond = 15, shift = 0.3) {
  true_ctrl <- rnorm(n_per_cond)
  true_trt <- rnorm(n_per_cond)
  ctrl <- data.frame(
    site = site_name, condition = "control",
```

```

    item1 = true_ctrl + rnorm(n_per_cond, sd = 0.6),
    item2 = true_ctrl + rnorm(n_per_cond, sd = 0.6),
    item3 = true_ctrl + rnorm(n_per_cond, sd = 0.6),
    item4 = true_ctrl + rnorm(n_per_cond, sd = 0.6)
  )
  trt <- data.frame(
    site = site_name, condition = "treatment",
    item1 = true_trt + rnorm(n_per_cond, sd = 0.6) + shift,
    item2 = true_trt + rnorm(n_per_cond, sd = 0.6) + shift,
    item3 = true_trt + rnorm(n_per_cond, sd = 0.6) + shift,
    item4 = true_trt + rnorm(n_per_cond, sd = 0.6) + shift
  )
  rbind(ctrl, trt)
}
ml_data <- do.call(rbind, lapply(
  c("SiteA", "SiteB", "SiteC", "SiteD"), gen_site
))

result <- multisite_ltg_smd(
  data = ml_data,
  site_var = "site",
  group_var = "condition",
  items = paste0("item", 1:4),
  reference_strategy = "pooled_across_sites",
  min_n_per_group = 10
)
print(result)

```

sensitivity_reference *Sensitivity of the LTG-SMD to the choice of target reference*

Description

Recomputes the LTG-SMD under each of several user-supplied alternative reference data frames. Useful when more than one target reference is defensible (Section 8.3 of the companion paper).

Usage

```

sensitivity_reference(
  object,
  alternative_references,
  study_data,
  group_var,
  score_var = NULL,
  items = NULL,
  group_levels = NULL,
  rho_external = NULL
)

```

Arguments

`object` An "ltg_smd" object computed with a primary reference.
`alternative_references` A named list of reference data frames. Names are used as labels in the output.
`study_data` Original study data (required to recompute).
`group_var, score_var, items, group_levels, rho_external` Arguments to pass through to [compute_ltg_smd\(\)](#).

Value

A data frame with columns `reference`, `ltg_smd`, `c_focal`, `c_reference`, `rho_focal`, `rho_reference`, including the primary reference in the first row.

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