# An Introduction to Data Visualization for Meta-Analyses with `tidymeta`

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`tidymeta` requires the development version of several packages, including `ggplot2`, to function correctly. You can install the required packages for this vignette with the following code:

```r
install.packages(c("devtools", "yaml", "ggrepel"))
library(devtools)
install_github("r-lib/rlang")
install_github("malcolmbarrett/tidymeta")
install_github("malcolmbarrett/mbmisc")
install_github("tidyverse/ggplot2")
```

## Tidy Meta-Analysis

`tidymeta` is a toolkit for working with meta-analyses in R. Currently, it includes a data set, called `iud_cxca`, for a meta-analysis of the relationship between IUD use and cervical cancer.

```r
iud_cxca
```

```
## # A tibble: 16 x 26
##    study_id study_name    author    es    l95   u95    lnes  lnl95   lnu95
##       <int> <chr>         <chr>  <dbl>  <dbl> <dbl>   <dbl>  <dbl>   <dbl>
##  1        1 Roura, 2016   Roura  0.600 0.300  1.20  -0.511  -1.20   0.182
##  2        2 Lassise, 1991 Lassi~ 0.800 0.500  1.20  -0.223  -0.693  0.182
##  3        3 Li, 2000      Li     0.890 0.730  1.08  -0.117  -0.315  0.0770
##  4        4 Shields, 2004 Shiel~ 0.500 0.300  0.820 -0.693  -1.20  -0.198
##  5        5 Castellsague~ Caste~ 0.630 0.380  1.06  -0.462  -0.968  0.0583
##  6        6 Castellsague~ Caste~ 0.450 0.300  0.670 -0.799  -1.20  -0.400
##  7        7 Brinton, 1990 Brint~ 0.690 0.500  0.900 -0.371  -0.693 -0.105
##  8        8 Parazzini, 1~ Paraz~ 0.600 0.300  1.10  -0.511  -1.20   0.0953
##  9        9 Williams, 19~ Willi~ 1.00  0.600  1.60   0.     -0.511  0.470
## 10       10 Hammouda, 20~ Hammo~ 0.300 0.100  0.500 -1.20   -2.30  -0.693
## 11       11 Castellsague~ Caste~ 1.08  0.370  3.20   0.0770 -0.994  1.16
## 12       12 Castellsague~ Caste~ 0.340 0.0500 2.56  -1.08   -3.00   0.940
## 13       13 Castellsague~ Caste~ 0.870 0.340  2.23  -0.139  -1.08   0.802
## 14       14 Castellsague~ Caste~ 0.490 0.190  1.23  -0.713  -1.66   0.207
## 15       15 Castellsague~ Caste~ 0.240 0.0900 0.660 -1.43   -2.41  -0.416
## 16       16 Celentano, 1~ Celen~ 0.500 0.170  1.47  -0.693  -1.77   0.385
## # ... with 17 more variables: selnes <dbl>, group <fct>, case_num <dbl>,
## #   control_num <dbl>, start_recruit <dbl>, stop_recruit <dbl>,
## #   pub_year <dbl>, numpap <dbl>, ses <dbl>, gravidity <dbl>,
## #   lifetimepart <dbl>, coitarche <dbl>, hpvstatus <dbl>, smoking <dbl>,
## #   location <chr>, aair <dbl>, hpvrate <dbl>
```

`tidymeta` includes `broom` methods for cleaning meta-analysis results, although it currently only supports the `metafor` package. The `tidy()` function in `broom` puts results into a tidy data frame: one observation per row and one variable per column.

```r
library(metafor)
meta4 <- rma(yi = lnes, sei = selnes, data = iud_cxca)
tidy(meta4) %>%
  as_tibble() # for space
```

```
## # A tibble: 17 x 8
##    study   type    estimate std.error statistic  p.value conf.low conf.high
##    <chr>   <chr>      <dbl>     <dbl>     <dbl>    <dbl>    <dbl>     <dbl>
##  1 1       study    -0.511     0.354     -1.44   NA         -1.20     0.182
##  2 2       study    -0.223     0.223     -0.999  NA         -0.661    0.215
##  3 3       study    -0.117     0.0999    -1.17   NA         -0.312    0.0793
##  4 4       study    -0.693     0.257     -2.70   NA         -1.20    -0.190
##  5 5       study    -0.462     0.262     -1.77   NA         -0.975    0.0509
##  6 6       study    -0.799     0.205     -3.90   NA         -1.20    -0.397
##  7 7       study    -0.371     0.150     -2.47   NA         -0.665   -0.0772
##  8 8       study    -0.511     0.331     -1.54   NA         -1.16     0.139
##  9 9       study     0.        0.250      0.     NA         -0.490    0.490
## 10 10      study    -1.20      0.411     -2.93   NA         -2.01    -0.399
## 11 11      study     0.0770    0.550      0.140  NA         -1.00     1.16
## 12 12      study    -1.08      1.00      -1.07   NA         -3.05     0.889
## 13 13      study    -0.139     0.480     -0.290  NA         -1.08     0.801
## 14 14      study    -0.713     0.476     -1.50   NA         -1.65     0.221
## 15 15      study    -1.43      0.508     -2.81   NA         -2.42    -0.431
## 16 16      study    -0.693     0.550     -1.26   NA         -1.77     0.385
## 17 Overall summa~  -0.449     0.0941    -4.77    1.83e-6   -0.634   -0.265
```

`tidymeta` also includes wrapper functions for working with meta-analysis packages in the context of the tidyverse. The main function for this is `meta_analysis()`, which models and tidies the object, as well as storing the results in the `meta` column to facilitate other analysis.

```r
#  same as above but stores the meta-analysis object
iud_cxca %>%
  meta_analysis(yi = lnes, sei = selnes, slab = study_name)
```

```
## # A tibble: 17 x 10
##    study    type  estimate std.error statistic  p.value conf.low conf.high
##    <chr>    <chr>    <dbl>     <dbl>     <dbl>    <dbl>    <dbl>     <dbl>
##  1 Roura, ~ study  -0.511     0.354     -1.44   NA         -1.20     0.182
##  2 Lassise~ study  -0.223     0.223     -0.999  NA         -0.661    0.215
##  3 Li, 2000 study  -0.117     0.0999    -1.17   NA         -0.312    0.0793
##  4 Shields~ study  -0.693     0.257     -2.70   NA         -1.20    -0.190
##  5 Castell~ study  -0.462     0.262     -1.77   NA         -0.975    0.0509
##  6 Castell~ study  -0.799     0.205     -3.90   NA         -1.20    -0.397
##  7 Brinton~ study  -0.371     0.150     -2.47   NA         -0.665   -0.0772
##  8 Parazzi~ study  -0.511     0.331     -1.54   NA         -1.16     0.139
##  9 William~ study   0.        0.250      0.     NA         -0.490    0.490
## 10 Hammoud~ study  -1.20      0.411     -2.93   NA         -2.01    -0.399
## 11 Castell~ study   0.0770    0.550      0.140  NA         -1.00     1.16
## 12 Castell~ study  -1.08      1.00      -1.07   NA         -3.05     0.889
## 13 Castell~ study  -0.139     0.480     -0.290  NA         -1.08     0.801
## 14 Castell~ study  -0.713     0.476     -1.50   NA         -1.65     0.221
## 15 Castell~ study  -1.43      0.508     -2.81   NA         -2.42    -0.431
## 16 Celenta~ study  -0.693     0.550     -1.26   NA         -1.77     0.385
## 17 Overall  summ~  -0.449     0.0941    -4.77    1.83e-6   -0.634   -0.265
## # ... with 2 more variables: meta <list>, weight <dbl>
```

The benefit of this approach is that you can do meta-analyses with tidy tools in mind. For example, if I want to conduct a sub-group analysis, I can use the `group_by()` function from `dplyr`. Here, I'm grouping by `group`, a variable with information about study design.

```
ma <- iud_cxca %>%
  group_by(group) %>%
  meta_analysis(yi = lnes, sei = selnes, slab = study_name, exponentiate = TRUE)

ma
```

```
## # A tibble: 21 x 11
##    group    study     type  estimate std.error statistic  p.value conf.low
##    <chr>    <chr>     <chr>    <dbl>     <dbl>     <dbl>    <dbl>    <dbl>
##  1 Nested ~ Roura, 2~ study    0.600    0.354     -1.44  NA          0.300
##  2 Nested ~ Subgroup~ summ~    0.600    0.354     -1.44   0.149      0.300
##  3 Populat~ Lassise,~ study    0.800    0.223     -0.999 NA          0.516
##  4 Populat~ Li, 2000  study    0.890    0.0999    -1.17  NA          0.732
##  5 Populat~ Shields,~ study    0.500    0.257     -2.70  NA          0.302
##  6 Populat~ Castells~ study    0.630    0.262     -1.77  NA          0.377
##  7 Populat~ Castells~ study    0.450    0.205     -3.90  NA          0.301
##  8 Populat~ Subgroup~ summ~    0.655    0.146     -2.90   0.00374    0.492
##  9 Clinic-~ Brinton,~ study    0.690    0.150     -2.47  NA          0.514
## 10 Clinic-~ Parazzin~ study    0.600    0.331     -1.54  NA          0.313
## # ... with 11 more rows, and 3 more variables: conf.high <dbl>,
## #   meta <list>, weight <dbl>
```

You can also do sensitivy analyses and cumulative analyses with `sensitivity()` and `cumulative()`.

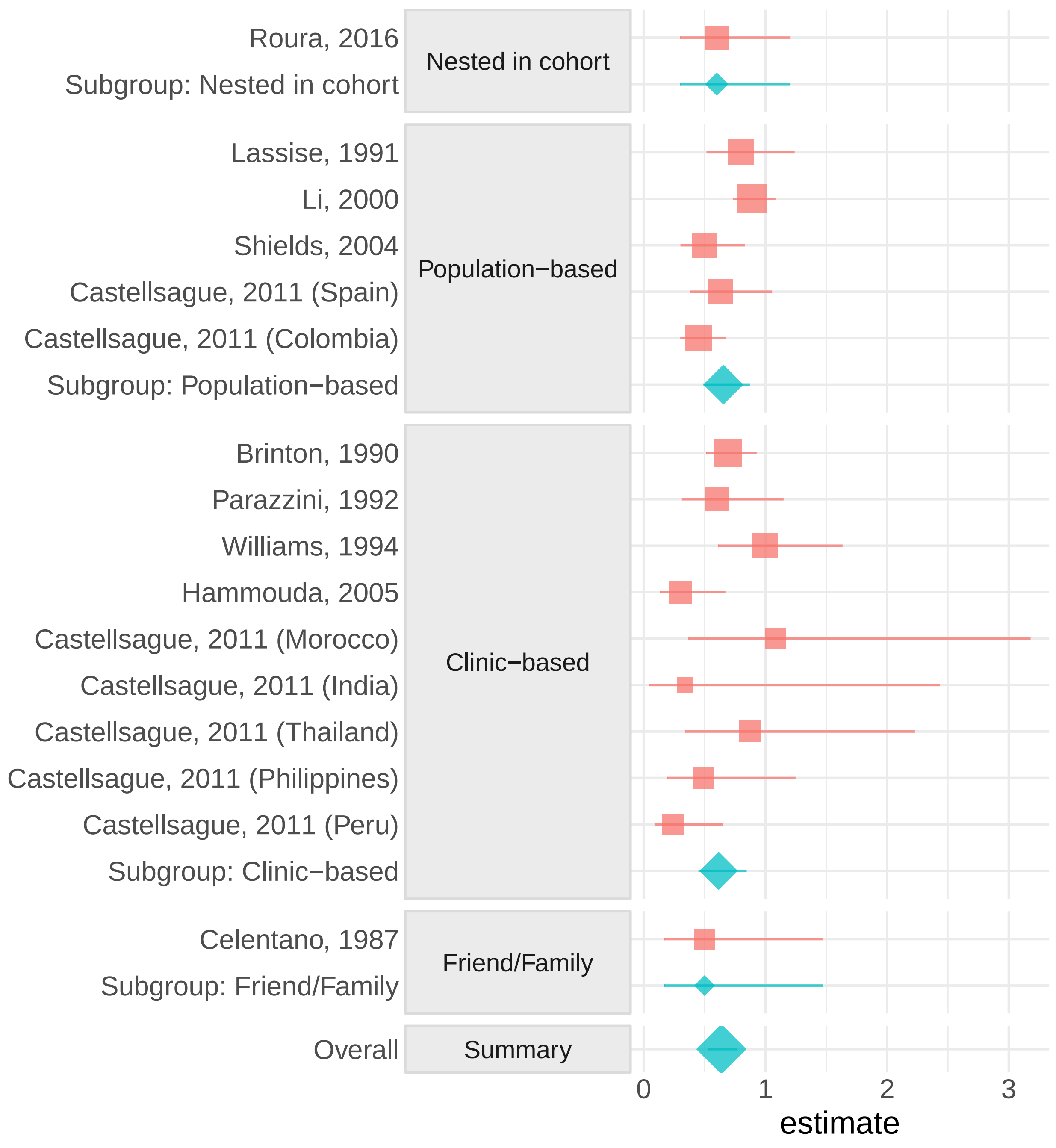
## Visualization for Meta-Analysis

`tidymeta` includes functionality for working with results in `ggplot2`, including meta-analysis specific geoms (such as `geom_funnel()`) and quick plots for common visualizations.

### Forest plots

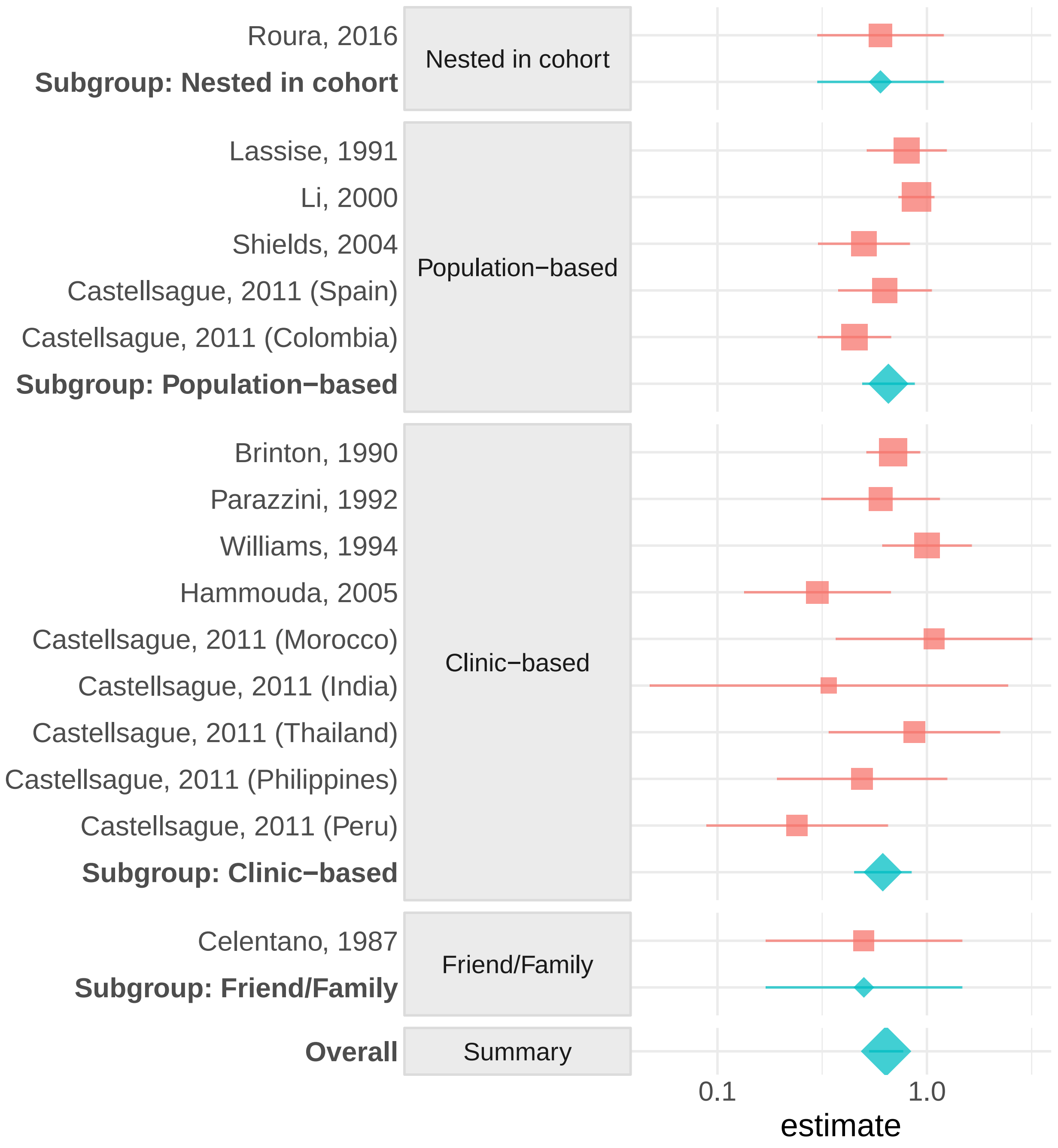
With tidy data, most data visualizations for meta-analyses are easy to build from the ground up. Nevertheless, `tidymeta` has several quick plot functions to make the process easier. `forest_plot()` takes a tidied meta-analysis and plots the effect sizes.

```
fp <- ma %>%
  forest_plot(group = group)

fp
```



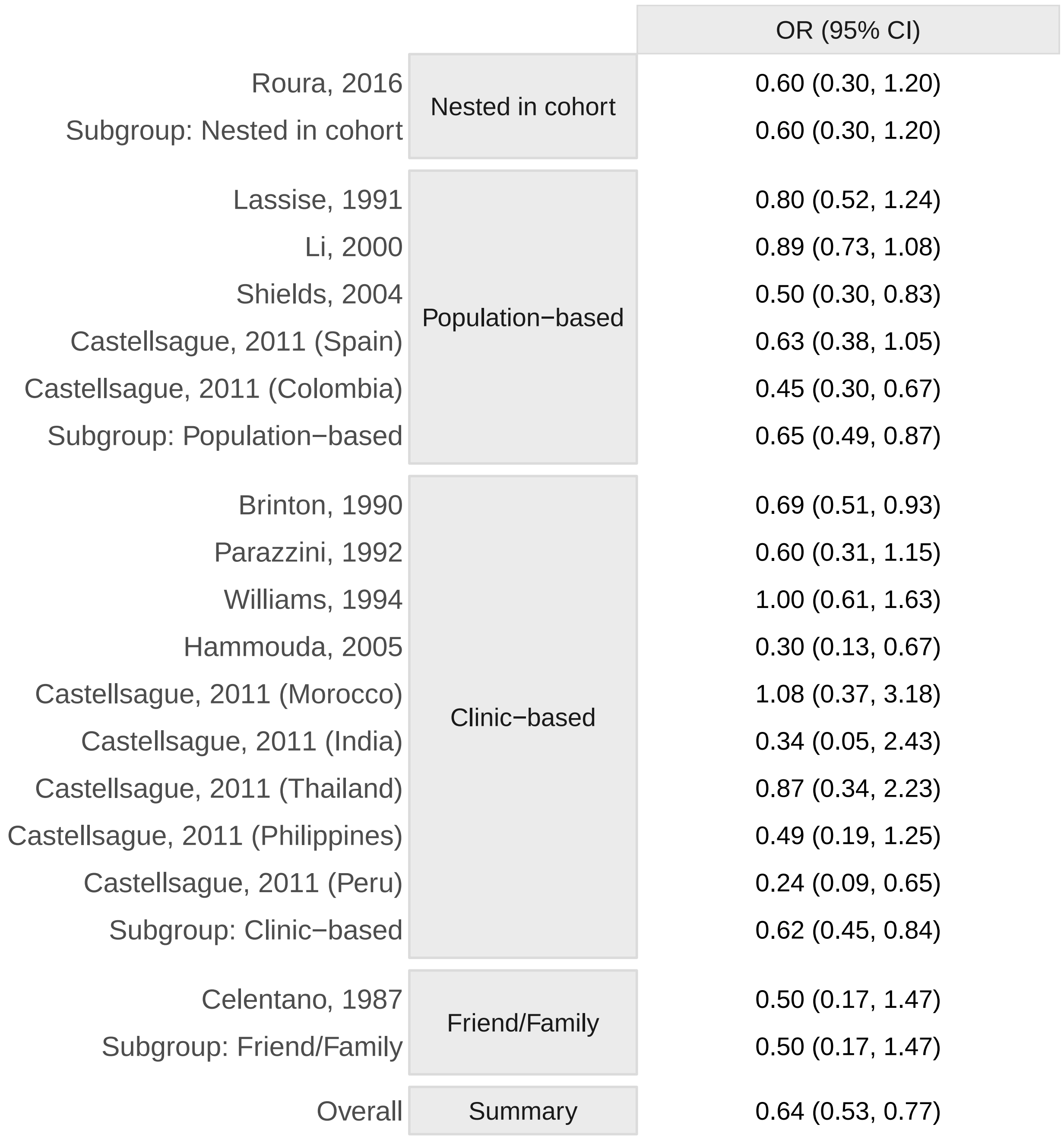
Because the results are still `ggplot2` objects, it's easy to make changes to the plot to your liking.

```
fp <- fp +
  scale_x_log() +
  theme(axis.text.y = element_text(face = c("bold", rep("plain", 21))))

fp
```



For better or worse, meta-analyses often have forest plots that include a lot of text about the studies in the form of a table. `text_table()` makes it easy to create a plot of text. `text_table()` quickly plots tables of text. Here, we'll format the OR and CI for the estimates using the `est_ci()` function from the `mbmisc` package.

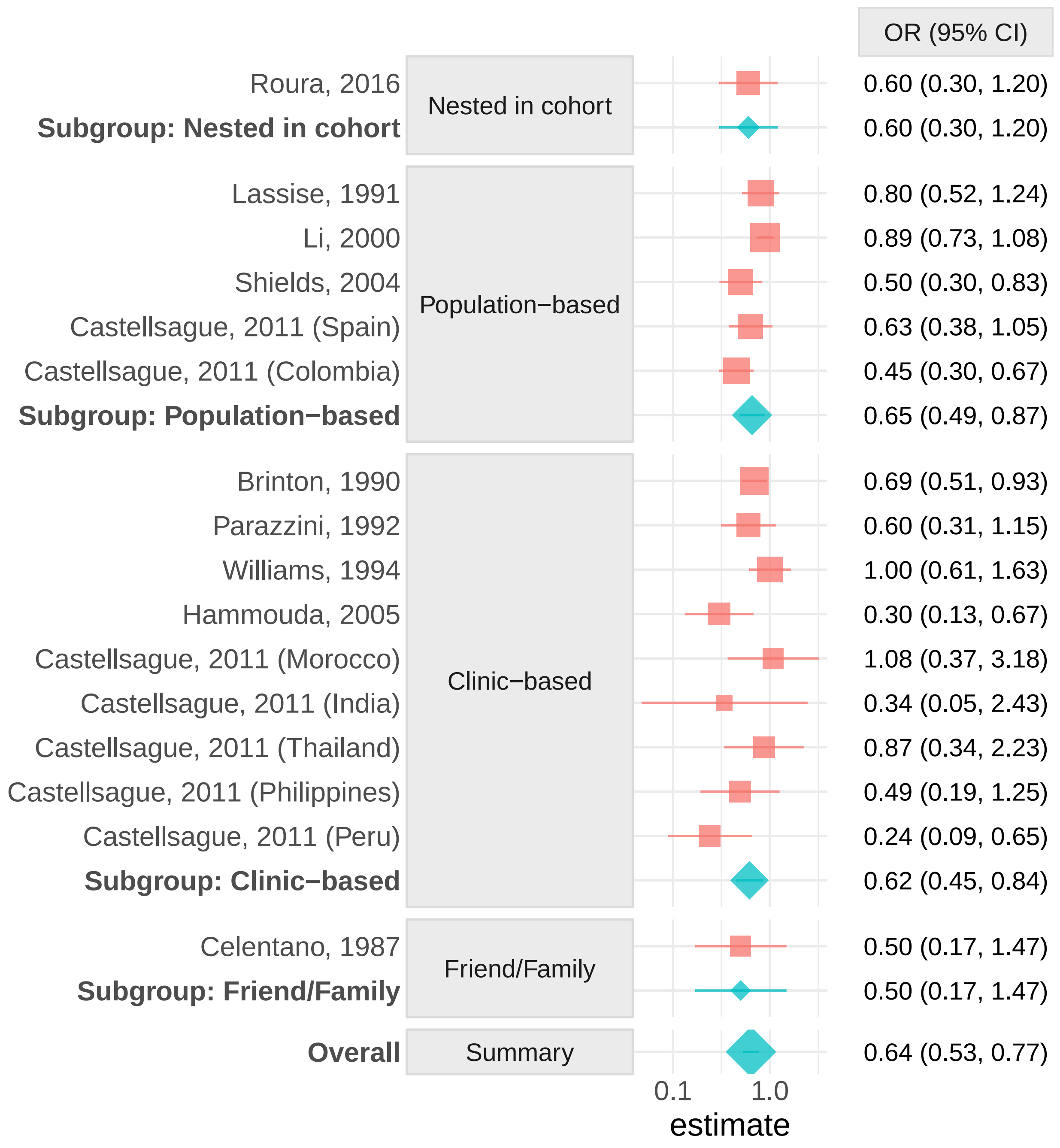
```r
library(mbmisc)
ma %>%
  mutate(est_95ci = est_ci(estimate, conf.low, conf.high, descriptor = "")) %>%
  text_table(group = group, "OR (95% CI)" = est_95ci)
```



| | | OR (95% CI) |
|---|---|---|
| Roura, 2016 | Nested in cohort | 0.60 (0.30, 1.20) |
| Subgroup: Nested in cohort | | 0.60 (0.30, 1.20) |
| Lassise, 1991 | Population−based | 0.80 (0.52, 1.24) |
| Li, 2000 | | 0.89 (0.73, 1.08) |
| Shields, 2004 | | 0.50 (0.30, 0.83) |
| Castellsague, 2011 (Spain) | | 0.63 (0.38, 1.05) |
| Castellsague, 2011 (Colombia) | | 0.45 (0.30, 0.67) |
| Subgroup: Population−based | | 0.65 (0.49, 0.87) |
| Brinton, 1990 | Clinic−based | 0.69 (0.51, 0.93) |
| Parazzini, 1992 | | 0.60 (0.31, 1.15) |
| Williams, 1994 | | 1.00 (0.61, 1.63) |
| Hammouda, 2005 | | 0.30 (0.13, 0.67) |
| Castellsague, 2011 (Morocco) | | 1.08 (0.37, 3.18) |
| Castellsague, 2011 (India) | | 0.34 (0.05, 2.43) |
| Castellsague, 2011 (Thailand) | | 0.87 (0.34, 2.23) |
| Castellsague, 2011 (Philippines) | | 0.49 (0.19, 1.25) |
| Castellsague, 2011 (Peru) | | 0.24 (0.09, 0.65) |
| Subgroup: Clinic−based | | 0.62 (0.45, 0.84) |
| Celentano, 1987 | Friend/Family | 0.50 (0.17, 1.47) |
| Subgroup: Friend/Family | | 0.50 (0.17, 1.47) |
| Overall | Summary | 0.64 (0.53, 0.77) |

Since we already have some of this information in the forest plot, we'll remove the y-axis and group labels. Then, we can use the `patchwork` package to combine the two easily.

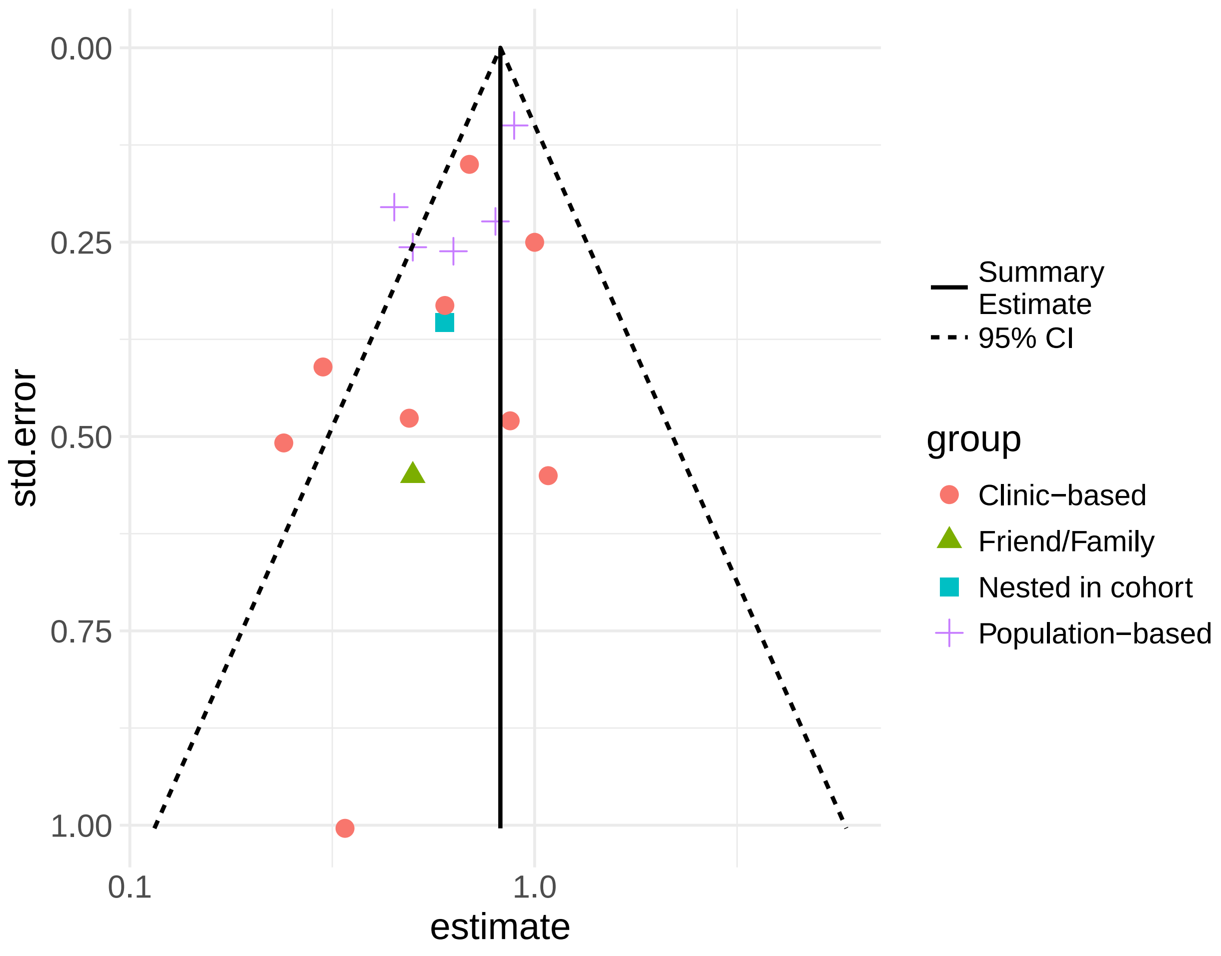
```r
library(patchwork)
txttbl <- ma %>%
  mutate(est_95ci = est_ci(estimate, conf.low, conf.high, descriptor = "")) %>%
  text_table(group = group, "OR (95% CI)" = est_95ci, show_y_facets = FALSE, show_y_axis = FALSE)

fp + txttbl
```



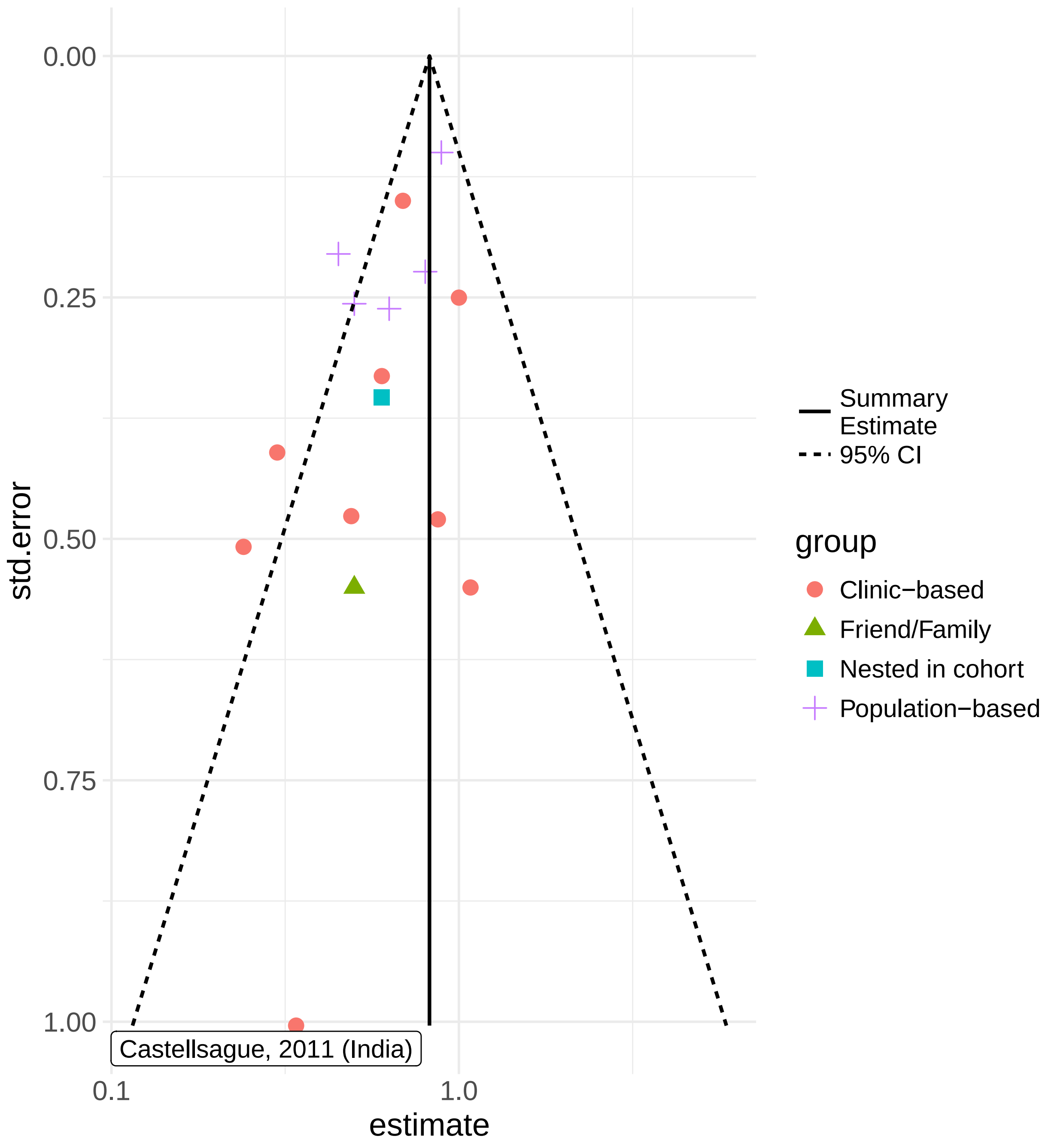
## Funnel plots

Other plots work just as easily. Although we can use the `geom_funnel()` function manually, a funnel plot can be made just as easily with `funnel_plot()`. Note that because this is an odds ratio, we need to treat to transform the funnel lines with `log_summary = TRUE`.

```
ma %>%
  funnel_plot(log_summary = TRUE, col = group, shape = group, size = 3)
```



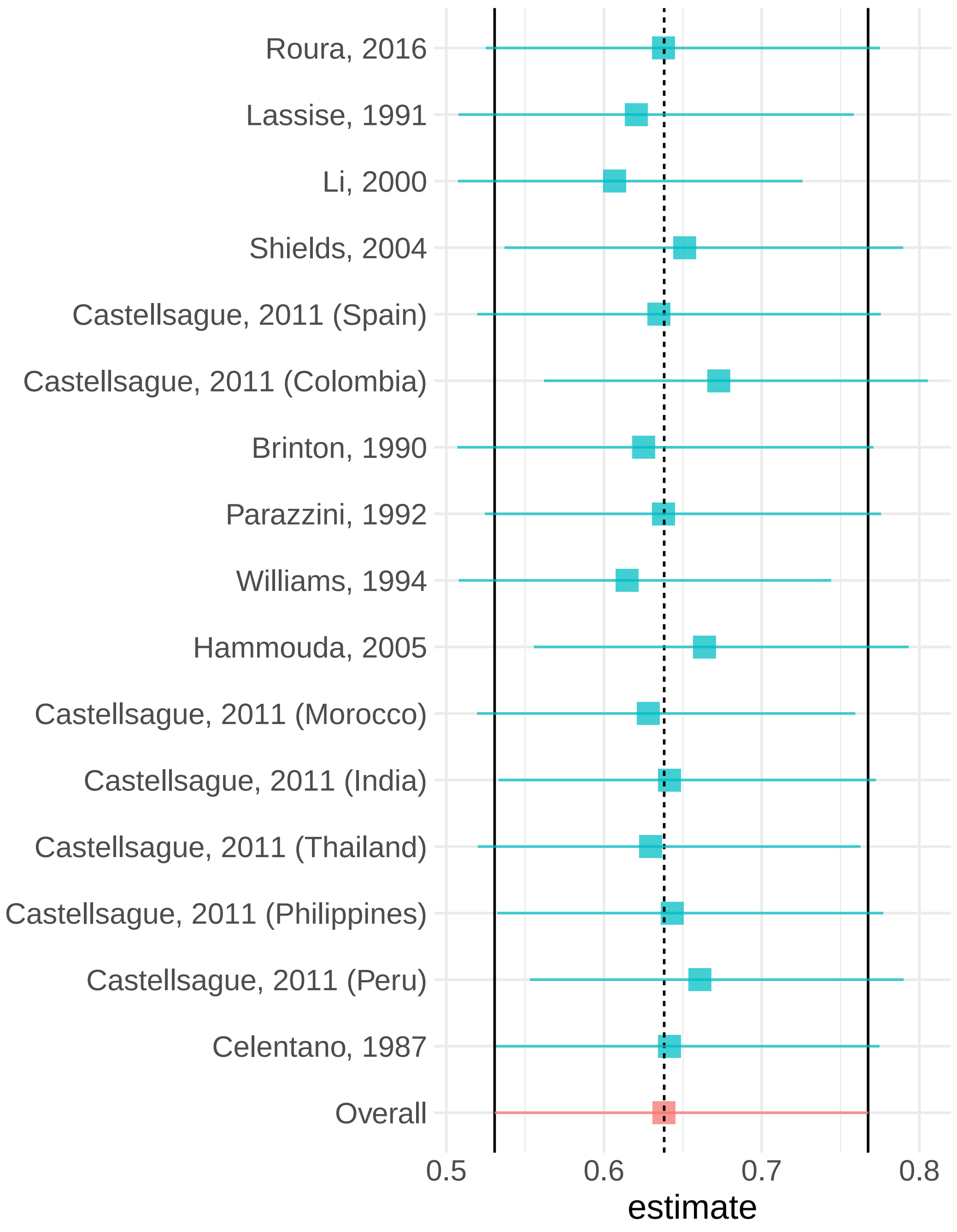
```r
library(ggrepel)

ma %>%
  mutate(se_label = ifelse(std.error > 1, study, "")) %>%
  funnel_plot(log_summary = TRUE, col = group, shape = group, size = 3) +
  geom_label_repel(aes(label = se_label), col = "black")
```



## Influence plots

You can use `sensitvity()` to assess the effect of leaving a study out in the summary estimate (the default) or comparing groups (by using `group_by()` first). You can plot the results with `influence_plot()`.

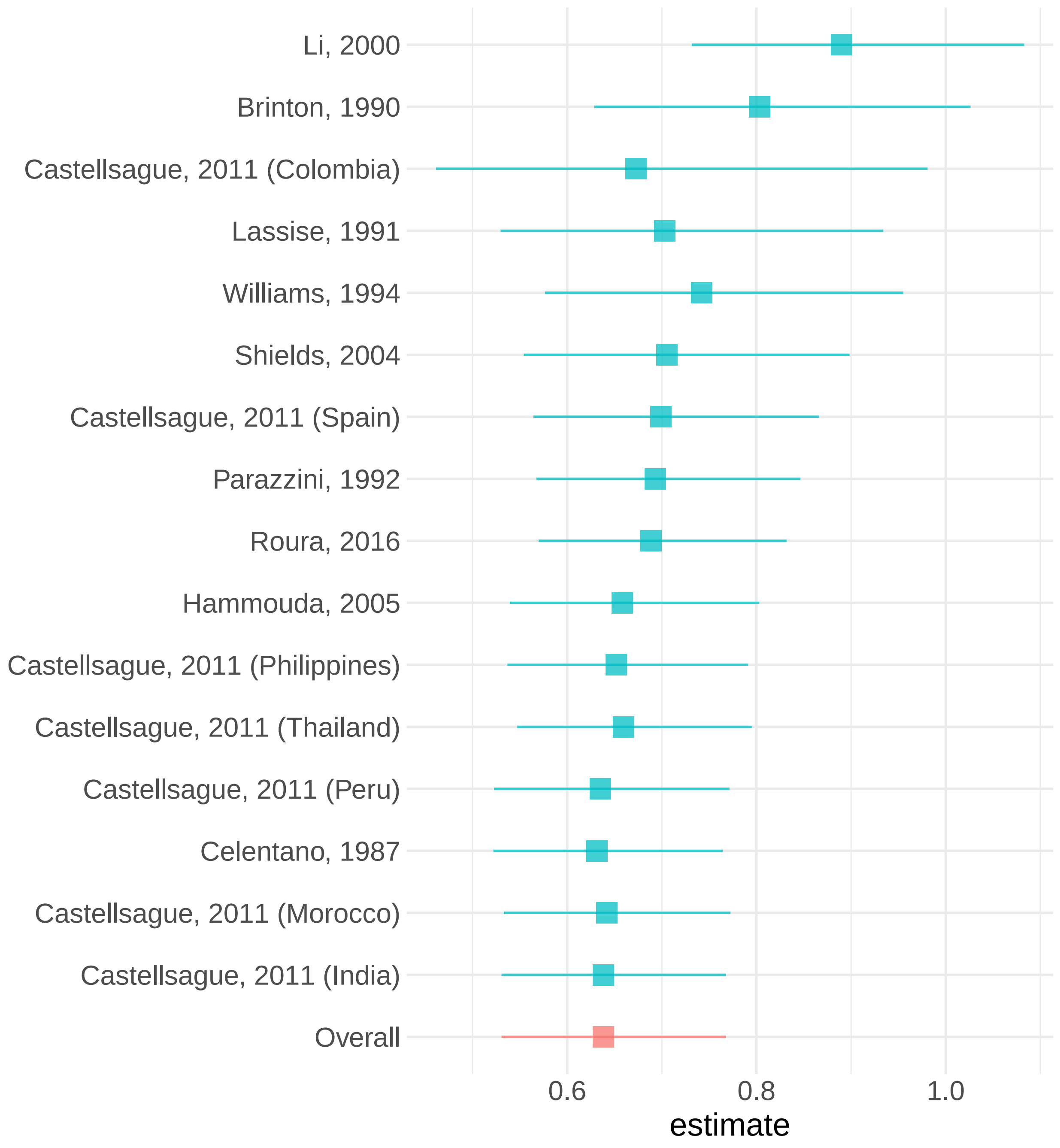
```
ma %>%
  sensitivity(exponentiate = TRUE) %>%
  influence_plot()
```



## Cumulative plots

A different way to approach sensitivy analysis is to order the studies in a given way and assess the cumulative effect on the summary estimate. For instance, let's order the analysis by study weight using `arrange()` from `dplyr`:

```
ma %>%
  arrange(desc(weight)) %>%
  cumulative(exponentiate = TRUE) %>%
  cumulative_plot(sum_lines = FALSE)
```


Li, 2000
Brinton, 1990
Castellsague, 2011 (Colombia)
Lassise, 1991
Williams, 1994
Shields, 2004
Castellsague, 2011 (Spain)
Parazzini, 1992
Roura, 2016
Hammouda, 2005
Castellsague, 2011 (Philippines)
Castellsague, 2011 (Thailand)
Castellsague, 2011 (Peru)
Celentano, 1987
Castellsague, 2011 (Morocco)
Castellsague, 2011 (India)
Overall
0.6
0.8
1.0
estimate