Apathy and Physical Activity: Meta-Analysis

Lahart IM, Boisgontier MP

26 de March, 2024

Contents

R Markdown file set-up

Packages required: 1) dmetar 2) tidyverse 3) meta 4) metafor 5) metasens 6) esc

Data file glimpse (not included in PDF)

Meta-analysis method

In a meta-analysis, we pooled Pearson product-moment correlations from eligible studies to examine the relationship between apathy and physical activity. Correlations were pooled using the generic inverse pooling method via the 'metacor' function in the R 'meta' package (Schwarzer et al., 2023a). This function automatically performs a necessary Fisher's z-transformation on the original, untransformed correlations prior to pooling. The 'metacor' function also reconverts the pooled association back to its original form for ease of interpretation. We used the 'metafor' package (Vietchbauer, 2010, 2023) to compare our three-level model to one in which a level was removed to investigate if our three-level model represented the variability in our data better than a two-level model. We anticipated considerable between-study heterogeneity, and therefore used a random-effects model to pool correlations. The restricted maximum likelihood (RML) estimator (Viechtbauer et al., 2005) was used to calculate the heterogeneity variance Tau2. In addition to Tau2, to quantify between study heterogeneity, we report the I2 statistic, which provides the percentage of variability in the correlations that is not caused by sampling error (Higgins et al., 2002). The I2 statistic was interpreted as follows: 0-40%, may not be important; 30-60%, may represent moderate heterogeneity; 50-90%, may represent substantial heterogeneity; and 75-100%, may represent considerable heterogeneity. To reduce the risk of false positives, we used a Knapp-Hartung adjustment (Knapp et al.,2003) to calculate the confidence interval around the pooled association. We also report the prediction interval, which provides a range within which we can expect the associations of future studies to fall based on the current evidence. The pooled correlation was interpreted using Cohen's conventions (Cohen et al., 1998): r -0.10, small negative correlation; r -0.30, moderate negative correlation; r -0.50, large negative correlation. Egger's regression test of funnel plot asymmetry (Egger et al., 1997) and a p-curve analysis (Simonsohn et al., 2014) were conducted to assess potential publication bias in our meta-analysis.

A secondary meta-analysis was conducted using the same approach, but based on Spearman's rho values, to further test the relationship between apathy and physical activity.

Subgroup analyses were conducted to examine the differences in correlations between studies including participants with different health conditions and using different types of physical activity outcomes, and apathy measures.

Meta-regressions were conducted to examine if the average age of participants or the proportion of women in a study predicted the reported correlation between apathy and physical activity. Another meta-regression was used as a sensitivity analysis to examine whether the quality of the studies affected the correlation.

All analyses were performed in RStudio integrated development environment (IDE) (2023.06.1+524, "Mountain Hydrangea" release) for R software environment (R Core Team, 2023) using the 'meta' (Schwarzer, 2023a), 'metasens' (Schwarzer et al., 2023b), and 'metafor' (Vietchbauer, 2010, 2023) R packages.

Meta-analysis: primary analysis

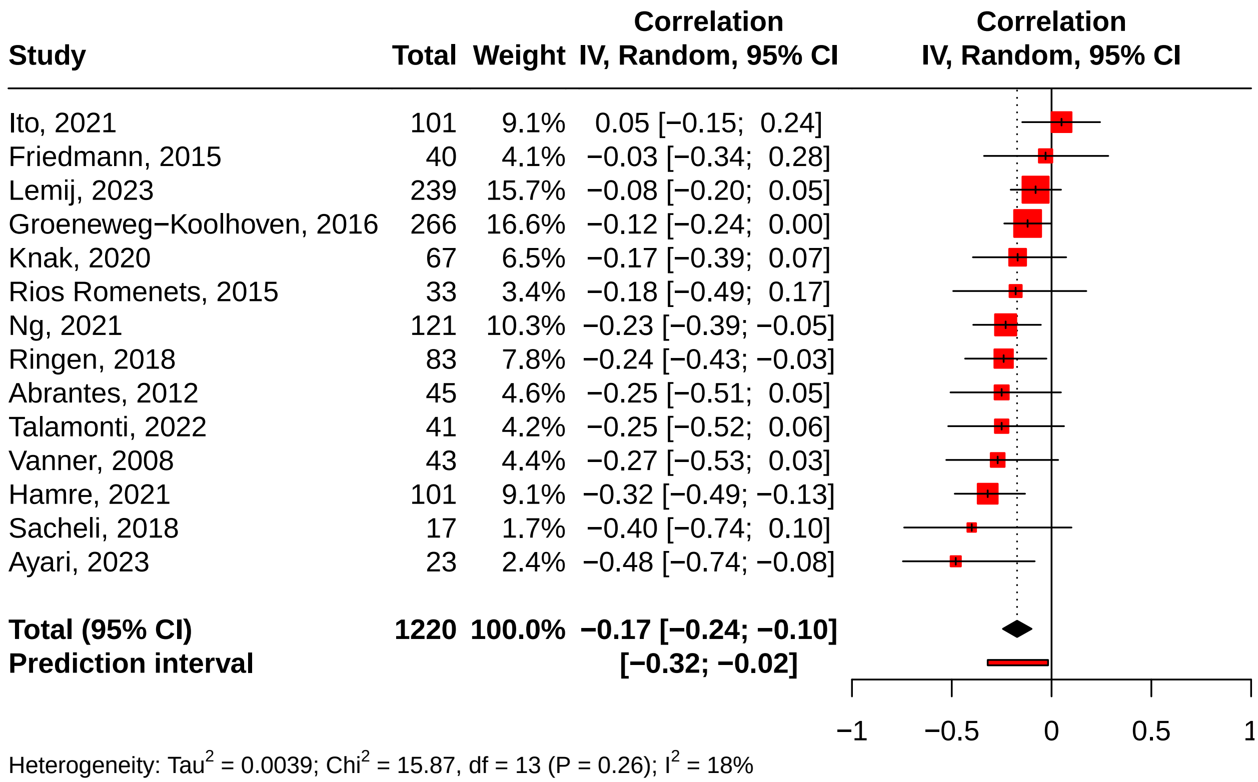
```r
m.cor <- metacor(cor = cor,
                 n = n,
                 studlab = author,
                 data = apathy_r,
                 fixed = FALSE,
                 random = TRUE,
                 method.tau = "REML",
                 hakn = TRUE,
                 title = "Apathy and physical activity behaviour")
summary(m.cor)
```

```
## Review:     Apathy and physical activity behaviour
```

```
##
##                               COR            95%-CI %W(random)
## Vanner, 2008              -0.2700 [-0.5276;  0.0330]        4.4
## Sacheli, 2018             -0.4000 [-0.7386;  0.0998]        1.7
## Ringen, 2018              -0.2400 [-0.4333; -0.0256]        7.8
## Ng, 2021                  -0.2300 [-0.3924; -0.0537]       10.3
## Abrantes, 2012            -0.2500 [-0.5064;  0.0470]        4.6
## Rios Romenets, 2015       -0.1800 [-0.4929;  0.1741]        3.4
## Friedmann, 2015           -0.0300 [-0.3383;  0.2842]        4.1
## Talamonti, 2022           -0.2500 [-0.5178;  0.0625]        4.2
## Ayari, 2023               -0.4800 [-0.7448; -0.0845]        2.4
## Groeneweg-Koolhoven, 2016 -0.1200 [-0.2369;  0.0003]       16.6
## Hamre, 2021               -0.3200 [-0.4851; -0.1329]        9.1
## Ito, 2021                  0.0500 [-0.1469;  0.2431]        9.1
## Knak, 2020                -0.1700 [-0.3941;  0.0732]        6.5
## Lemij, 2023               -0.0800 [-0.2048;  0.0474]       15.7
##
## Number of studies: k = 14
## Number of observations: o = 1220
##
##                          COR            95%-CI     t p-value
## Random effects model -0.1728 [-0.2437; -0.1002] -5.09  0.0002
##
## Quantifying heterogeneity:
##  tau^2 = 0.0039 [0.0000; 0.0321]; tau = 0.0626 [0.0000; 0.1791]
##  I^2 = 18.1% [0.0%; 55.8%]; H = 1.11 [1.00; 1.50]
##
## Test of heterogeneity:
##      Q d.f. p-value
##  15.87   13  0.2560
##
## Details on meta-analytical method:
## - Inverse variance method
## - Restricted maximum-likelihood estimator for tau^2
## - Q-Profile method for confidence interval of tau^2 and tau
## - Hartung-Knapp adjustment for random effects model (df = 13)
## - Fisher's z transformation of correlations
```

Our meta-analysis of 14 studies (n = 1220) based on Pearson's r revealed a statistically significant small to moderate negative correlation between apathy and physical activity (r = -0.17; 95% confidence interval [95% CI]: -0.24 to -0.10; p = 0.0002). Further supporting this result, between-study statistical heterogeneity could be considered as not important (Tau2 = 0.004, 95% CI: 0.000 to 0.032; I2 = 18.1%, 95% CI: 0.0 to 55.8%), and the prediction interval ranged from r = -0.32 to -0.02, suggesting that the true effect size is at least small, and that the correlation is expected to be negative for a future study.

```r
forest(m.cor,
            layout = "Revman5",
            sortvar = -TE,
            prediction = TRUE,
            print.tau2 = FALSE,
            leftlabs = c("Author", "n"),
            xlim=c(-1.0,1.0),
            fs.hetstat = 10,
            addrows.below.overall = 2)
```




```
png(file = "Main analysis forestplot.png",
    width = 2800, height = 3800, res = 300)

forest(m.cor,
            layout = "Revman5",
            sortvar = -TE,
            prediction = TRUE,
            print.tau2 = FALSE,
            leftlabs = c("Author", "n"),
            xlim=c(-1.0,1.0),
            fs.hetstat = 10,
            addrows.below.overall = 2)

dev.off()
```

```
## pdf
##   2
```

Secondary analysis based on Spearman's rho values

Analysis with metafor with model comparisons

```
mv.cor.rho <- rma.mv(yi = z,
                V = var.z,
                slab = author,
                data = apathy_rho,
                random = ~ 1 | author/cor_id,
                test = "t",
                method = "REML")
```

```r
summary(mv.cor.rho)
```

```
##
## Multivariate Meta-Analysis Model (k = 7; method: REML)
##
##   logLik  Deviance       AIC       BIC      AICc
##   1.3899   -2.7798    3.2202    2.5955   15.2202
##
## Variance Components:
##
##             estim    sqrt  nlvls  fixed         factor
## sigma^2.1  0.0973  0.3119      4     no         author
## sigma^2.2  0.0000  0.0000      7     no  author/cor_id
##
## Test for Heterogeneity:
## Q(df = 6) = 33.4420, p-val < .0001
##
## Model Results:
##
## estimate      se     tval  df    pval    ci.lb    ci.ub
##  -0.4275  0.1678  -2.5474   6  0.0436  -0.8381  -0.0169  *
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
round(convert_z2r(-0.4275), 3) # point estimate
```

```
## [1] -0.403
```

```r
round(convert_z2r(-0.8381), 3) # lower CI
```

```
## [1] -0.685
```

```r
round(convert_z2r(-0.0169), 3) # Upper CI
```

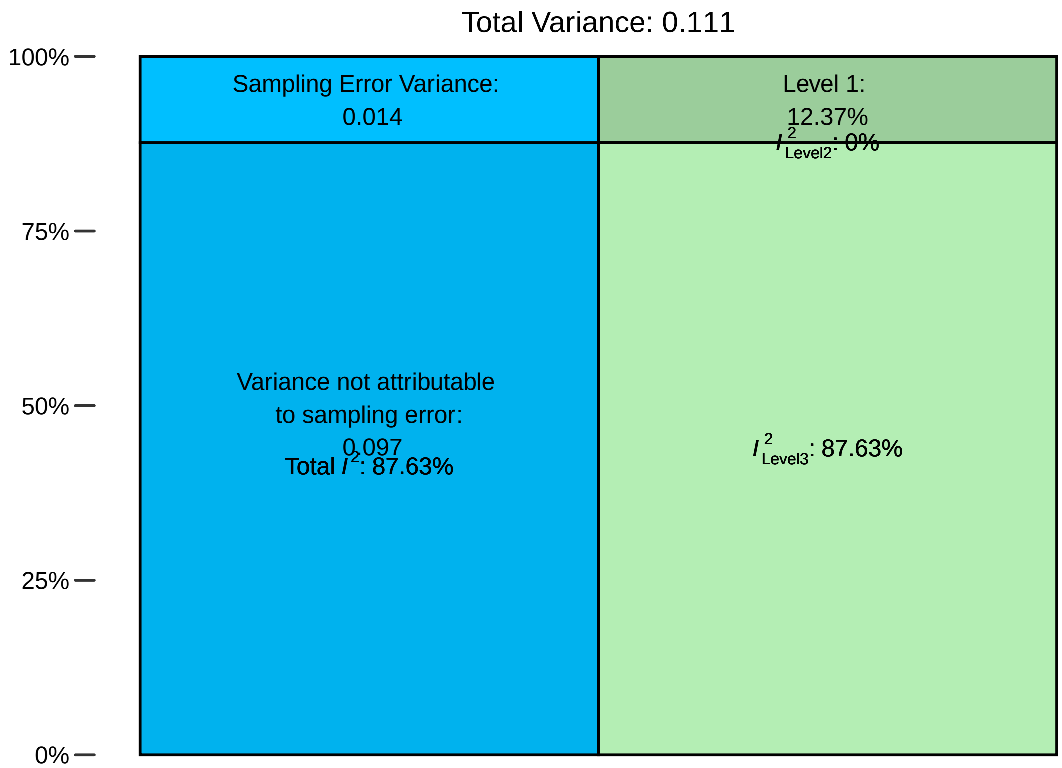
```
## [1] -0.017
```

Explore heterogeneity

```r
i2 <- var.comp(mv.cor.rho)
summary(i2)
```

```
##         % of total variance    I2
## Level 1        1.236966e+01   ---
## Level 2        3.468176e-09     0
## Level 3        8.763034e+01 87.63
## Total I2: 87.63%
```

```r
plot(i2)
```



Comparing models

Reduced model in which the level 3 variance (between study heterogeneity) is set to 0, which assumes all effect sizes are independent.

```
l3.removed <- rma.mv(yi = z,
                     V = var.z,
                     slab = author,
                     data = apathy_rho,
                     random = ~ 1 | author/cor_id,
                     test = "t",
                     method = "REML",
                     sigma2 =  c(0, NA))

summary(l3.removed)
```

```
##
## Multivariate Meta-Analysis Model (k = 7; method: REML)
##
##   logLik  Deviance       AIC       BIC      AICc
##  -1.2868    2.5736    6.5736    6.1572   10.5736
##
## Variance Components:
##
##              estim    sqrt  nlvls  fixed         factor
## sigma^2.1   0.0000  0.0000      4    yes         author
## sigma^2.2   0.0716  0.2676      7     no  author/cor_id
##
## Test for Heterogeneity:
## Q(df = 6) = 33.4420, p-val < .0001
```

```
##
## Model Results:
##
## estimate      se     tval  df    pval    ci.lb    ci.ub
##  -0.3346  0.1116  -2.9987   6  0.0240  -0.6076  -0.0616  *
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparing full and reduced models.

```
anova(mv.cor.rho, l3.removed)
```

```
##
##         df    AIC    BIC    AICc  logLik    LRT   pval      QE
## Full     3 3.2202 2.5955 15.2202  1.3899               33.4420
## Reduced  2 6.5736 6.1572 10.5736 -1.2868 5.3535 0.0207 33.4420
```

Secondary analysis of rho values with meta

```
m.cor.rho <- metacor(cor = cor,
                 n = n,
                 data = apathy_rho,
                 cluster = cluster,
                 studlab = author,
                 fixed = FALSE,
                 random = TRUE,
                 method.tau = "REML",
                 hakn = TRUE)
summary(m.cor.rho)
```

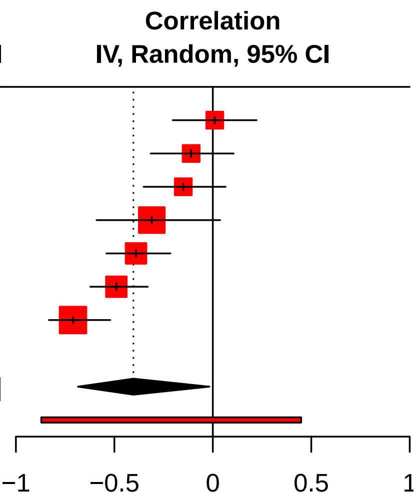
```
##                                   COR            95%-CI %W(random) cluster
## Farholm, 2017                -0.4900 [-0.6226; -0.3301]       13.8 study_1
## Farholm, 2017                -0.3900 [-0.5405; -0.2153]       13.8 study_1
## Ersoz Huseyinsinoglu, 2017 -0.1500 [-0.3519;  0.0652]        9.3 study_2
## Ersoz Huseyinsinoglu, 2017  0.0100 [-0.2036;  0.2226]        9.3 study_2
## Ersoz Huseyinsinoglu, 2017 -0.1100 [-0.3157;  0.1056]        9.3 study_2
## Ishimaru, 2019               -0.7100 [-0.8328; -0.5207]       23.0 study_3
## Rios Romenets, 2015          -0.3100 [-0.5905;  0.0373]       21.6 study_4
##
## Number of studies: n = 4
## Number of estimates: k = 7
## Number of observations: o = 543
##
##                             COR            95%-CI     t p-value
## Random effects model -0.4033 [-0.6849; -0.0169] -2.55  0.0436
##
## Quantifying heterogeneity:
##  tau^2.1 = 0.0973 [0.0158; 0.9745]; tau.1 = 0.3119 [0.1259; 0.9872] (between cluster)
##  tau^2.2 < 0.0001 [0.0000; 0.0588]; tau.2 < 0.0001 [0.0000; 0.2424] (within cluster)
##  I^2 = 82.0% [64.1%; 91.0%]; H = 2.36 [1.67; 3.34]
##
## Test of heterogeneity:
##      Q d.f.  p-value
##  33.39    6 < 0.0001
```

```
##
## Details on meta-analytical method:
## - Inverse variance method (three-level model)
## - Restricted maximum-likelihood estimator for tau^2
## - Profile-Likelihood method for confidence interval of tau^2 and tau
## - Random effects confidence interval based on t-distribution (df = 6)
## - Fisher's z transformation of correlations
```

Results of the secondary meta-analysis based on seven Spearman rho values (k = 4, n = 543) were consistent with those based on Pearson's r as they showed a statistically significant moderate negative correlation between apathy and physical activity (r = -0.40; 95% CI: -0.68 to -0.02; p = 0.043). However, we observed substantial to considerable between-study statistical heterogeneity (between-cluster Tau2 = 0.09, 95% CI: 0.01 to 0.97; I2 = 82.0%, 95% CI: 64.1 to 91.0%), and the prediction interval ranged from r = -0.87 to 0.45, indicating that a moderate positive correlation cannot be ruled out for future studies.

```r
forest(m.cor.rho,
            layout = "Revman5",
            sortvar = -TE,
            prediction = TRUE,
            print.tau2 = FALSE,
            fontsize = 11,
            xlim=c(-1.0,1.0),
            fs.hetstat = 10,
            addrows.below.overall = 2)
```

Study	Cluster	Total	Weight	Correlation IV, Random, 95% CI
Ersoz Huseyinsinoglu, 2017	study_2	85	9.3%	0.01 [−0.20; 0.22]
Ersoz Huseyinsinoglu, 2017	study_2	85	9.3%	−0.11 [−0.32; 0.11]
Ersoz Huseyinsinoglu, 2017	study_2	85	9.3%	−0.15 [−0.35; 0.07]
Rios Romenets, 2015	study_4	33	21.6%	−0.31 [−0.59; 0.04]
Farholm, 2017	study_1	106	13.8%	−0.39 [−0.54; −0.22]
Farholm, 2017	study_1	106	13.8%	−0.49 [−0.62; −0.33]
Ishimaru, 2019	study_3	43	23.0%	−0.71 [−0.83; −0.52]
Total (95% CI)		**543**	**100.0%**	**−0.40 [−0.68; −0.02]**
Prediction interval				**[−0.87; 0.45]**



Heterogeneity: $Tau^2 = 0.0973$; $Chi^2 = 33.39$, df = 6 (P < 0.01); $I^2 = 82\%$

```r
png(file = "Rho analysis forestplot.png",
    width = 2500, height = 2000, res = 300)

forest(m.cor.rho,
            layout = "Revman5",
            sortvar = -TE,
            prediction = TRUE,
            print.tau2 = FALSE,
            fontsize = 11,
            xlim=c(-1.0,1.0),
            fs.hetstat = 10,
            addrows.below.overall = 2)
```

```r
dev.off()
```

```
## pdf
##   2
```

Meta-analysis: subgroup analyses

Subgroup analysis by health status

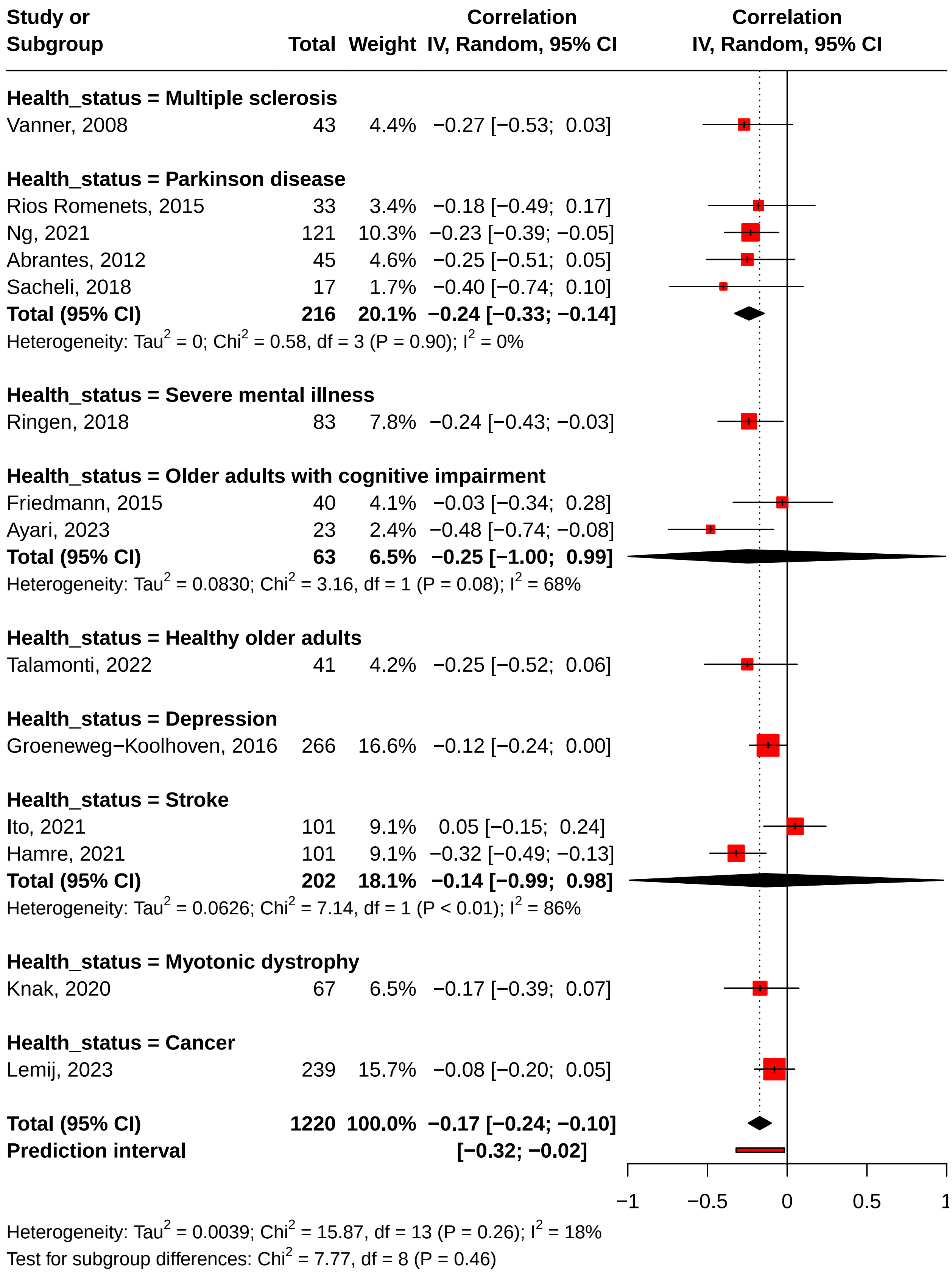
```r
apathy_r$Health_status <- as.factor(apathy_r$Health_status)

Health_subg <- update(m.cor,
            subgroup = Health_status,
            tau.common = FALSE)
Health_subg
```

```
## Review:     Apathy and physical activity behaviour
##
## Number of studies: k = 14
## Number of observations: o = 1220
##
##                          COR             95%-CI     t p-value
## Random effects model -0.1728 [-0.2437; -0.1002] -5.09  0.0002
##
## Quantifying heterogeneity:
##  tau^2 = 0.0039 [0.0000; 0.0321]; tau = 0.0626 [0.0000; 0.1791]
##  I^2 = 18.1% [0.0%; 55.8%]; H = 1.11 [1.00; 1.50]
##
## Test of heterogeneity:
##      Q d.f. p-value
##  15.87   13  0.2560
##
## Results for subgroups (random effects model):
##                                                       k     COR
## Health_status = Multiple sclerosis                    1 -0.2700
## Health_status = Parkinson disease                     4 -0.2392
## Health_status = Severe mental illness                 1 -0.2400
## Health_status = Older adults with cognitive imp ...   2 -0.2479
## Health_status = Healthy older adults                  1 -0.2500
## Health_status = Depression                            1 -0.1200
## Health_status = Stroke                                2 -0.1399
## Health_status = Myotonic dystrophy                    1 -0.1700
## Health_status = Cancer                                1 -0.0800
##                                                                 95%-CI  tau^2
## Health_status = Multiple sclerosis                  [-0.5276;  0.0330]     --
## Health_status = Parkinson disease                   [-0.3294; -0.1446]      0
## Health_status = Severe mental illness               [-0.4333; -0.0256]     --
## Health_status = Older adults with cognitive imp ... [-0.9976;  0.9935] 0.0830
## Health_status = Healthy older adults                [-0.5178;  0.0625]     --
## Health_status = Depression                          [-0.2369;  0.0003]     --
## Health_status = Stroke                              [-0.9883;  0.9795] 0.0626
## Health_status = Myotonic dystrophy                  [-0.3941;  0.0732]     --
## Health_status = Cancer                              [-0.2048;  0.0474]     --
```

```
##                                                         tau    Q   I^2
## Health_status = Multiple sclerosis                       -- 0.00    --
## Health_status = Parkinson disease                         0 0.58  0.0%
## Health_status = Severe mental illness                    -- 0.00    --
## Health_status = Older adults with cognitive imp ... 0.2881 3.16 68.3%
## Health_status = Healthy older adults                     -- 0.00    --
## Health_status = Depression                               -- 0.00    --
## Health_status = Stroke                               0.2503 7.14 86.0%
## Health_status = Myotonic dystrophy                       -- 0.00    --
## Health_status = Cancer                                   -- 0.00    --
##
## Test for subgroup differences (random effects model):
##                   Q d.f. p-value
## Between groups 7.77    8  0.4564
##
## Details on meta-analytical method:
## - Inverse variance method
## - Restricted maximum-likelihood estimator for tau^2
## - Q-Profile method for confidence interval of tau^2 and tau
## - Hartung-Knapp adjustment for random effects model (df = 13)
## - Fisher's z transformation of correlations
```

The test of subgroup differences between health status measures was possible between studies comprising people with Parkinson (k = 4), stroke (k = 2), and older adults with cognitive impairment (k = 2). We found statistical differences between these studies (p = 0.0002). The relationship between apathy and physical activity was statistically significant only in studies that included participants with Parkinson's disease (r = -0.22; 95% CI: -0.29 to -0.12).

```
forest(Health_subg,
            layout = "Revman",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1, 1),
            prediction = TRUE,
            fontsize = 11,
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)
```


Study or Subgroup
Total
Weight
Correlation IV, Random, 95% CI
Correlation IV, Random, 95% CI
Health_status = Multiple sclerosis
Vanner, 2008 43 4.4% −0.27 [−0.53; 0.03]
Health_status = Parkinson disease
Rios Romenets, 2015 33 3.4% −0.18 [−0.49; 0.17]
Ng, 2021 121 10.3% −0.23 [−0.39; −0.05]
Abrantes, 2012 45 4.6% −0.25 [−0.51; 0.05]
Sacheli, 2018 17 1.7% −0.40 [−0.74; 0.10]
Total (95% CI) 216 20.1% −0.24 [−0.33; −0.14]
Heterogeneity: Tau^2 = 0; Chi^2 = 0.58, df = 3 (P = 0.90); I^2 = 0%
Health_status = Severe mental illness
Ringen, 2018 83 7.8% −0.24 [−0.43; −0.03]
Health_status = Older adults with cognitive impairment
Friedmann, 2015 40 4.1% −0.03 [−0.34; 0.28]
Ayari, 2023 23 2.4% −0.48 [−0.74; −0.08]
Total (95% CI) 63 6.5% −0.25 [−1.00; 0.99]
Heterogeneity: Tau^2 = 0.0830; Chi^2 = 3.16, df = 1 (P = 0.08); I^2 = 68%
Health_status = Healthy older adults
Talamonti, 2022 41 4.2% −0.25 [−0.52; 0.06]
Health_status = Depression
Groeneweg−Koolhoven, 2016 266 16.6% −0.12 [−0.24; 0.00]
Health_status = Stroke
Ito, 2021 101 9.1% 0.05 [−0.15; 0.24]
Hamre, 2021 101 9.1% −0.32 [−0.49; −0.13]
Total (95% CI) 202 18.1% −0.14 [−0.99; 0.98]
Heterogeneity: Tau^2 = 0.0626; Chi^2 = 7.14, df = 1 (P < 0.01); I^2 = 86%
Health_status = Myotonic dystrophy
Knak, 2020 67 6.5% −0.17 [−0.39; 0.07]
Health_status = Cancer
Lemij, 2023 239 15.7% −0.08 [−0.20; 0.05]
Total (95% CI) 1220 100.0% −0.17 [−0.24; −0.10]
Prediction interval [−0.32; −0.02]
−1
−0.5
0
0.5
1
Heterogeneity: Tau^2 = 0.0039; Chi^2 = 15.87, df = 13 (P = 0.26); I^2 = 18%
Test for subgroup differences: Chi^2 = 7.77, df = 8 (P = 0.46)

```r
png(file = "Health condition forestplot.png",
    width = 2800, height = 3000, res = 300)

forest(Health_subg,
            layout = "Revman",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1, 1),
            prediction = TRUE,
            fontsize = 11,
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)

dev.off()
```

```
## pdf
##   2
```

Subgroup analysis by physical activity outcome

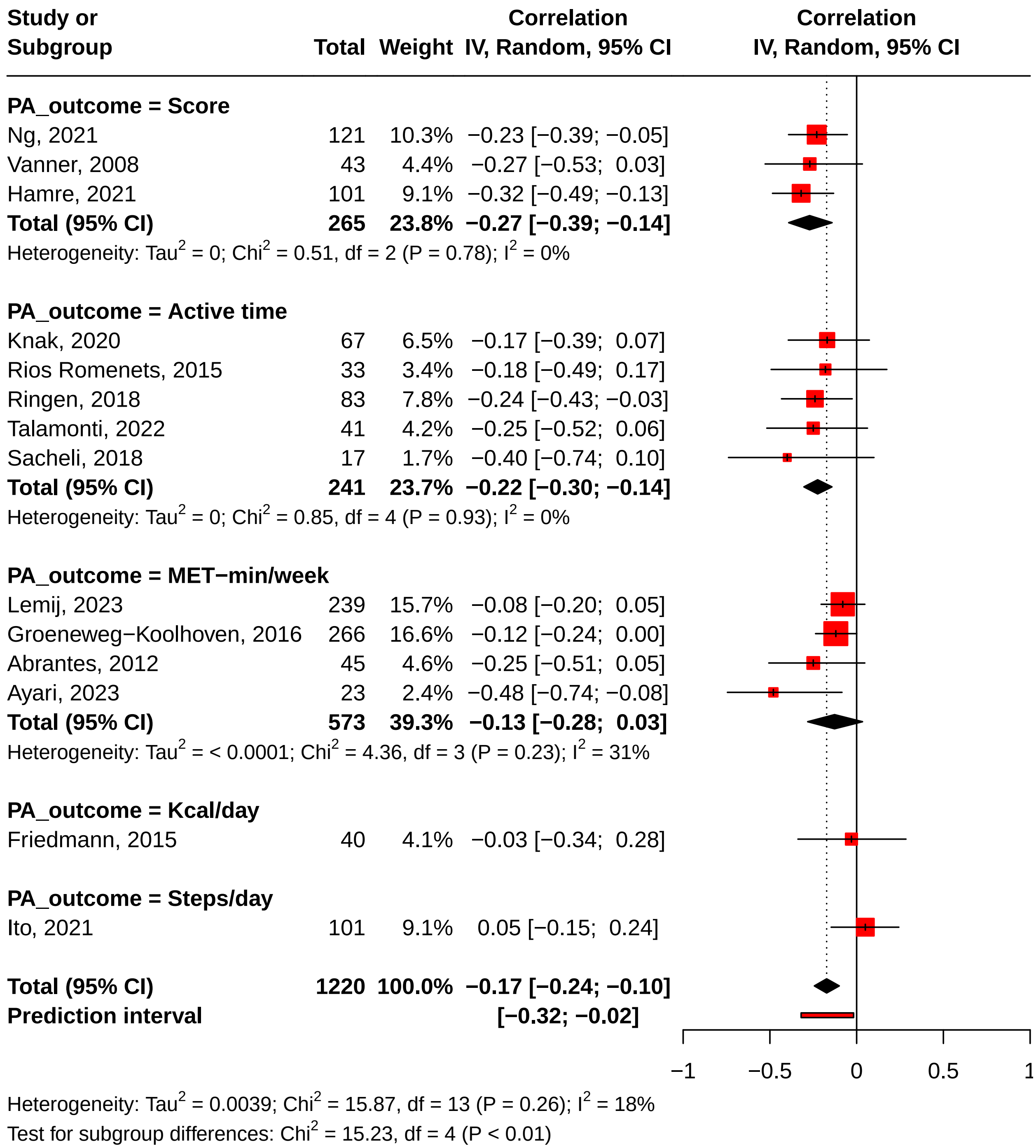
```r
apathy_r$PA_outcome <- as.factor(apathy_r$PA_outcome)

PAout_subg <- update(m.cor,
            subgroup = PA_outcome,
            tau.common = FALSE)
PAout_subg
```

```
## Review:     Apathy and physical activity behaviour
##
## Number of studies: k = 14
## Number of observations: o = 1220
##
##                          COR            95%-CI     t p-value
## Random effects model -0.1728 [-0.2437; -0.1002] -5.09  0.0002
##
## Quantifying heterogeneity:
##  tau^2 = 0.0039 [0.0000; 0.0321]; tau = 0.0626 [0.0000; 0.1791]
##  I^2 = 18.1% [0.0%; 55.8%]; H = 1.11 [1.00; 1.50]
##
## Test of heterogeneity:
##      Q d.f. p-value
##  15.87   13  0.2560
##
## Results for subgroups (random effects model):
##                             k     COR            95%-CI   tau^2    tau    Q
## PA_outcome = Score          3 -0.2712 [-0.3917; -0.1416]       0      0 0.51
## PA_outcome = Active time    5 -0.2247 [-0.3040; -0.1423]       0      0 0.85
## PA_outcome = MET-min/week   4 -0.1273 [-0.2821;  0.0339] <0.0001 0.0018 4.36
## PA_outcome = Kcal/day       1 -0.0300 [-0.3383;  0.2842]      --     -- 0.00
## PA_outcome = Steps/day      1  0.0500 [-0.1469;  0.2431]      --     -- 0.00
##                             I^2
## PA_outcome = Score         0.0%
## PA_outcome = Active time   0.0%
```

```
## PA_outcome = MET-min/week 31.1%
## PA_outcome = Kcal/day        --
## PA_outcome = Steps/day       --
##
## Test for subgroup differences (random effects model):
##                    Q d.f. p-value
## Between groups 15.23    4  0.0042
##
## Details on meta-analytical method:
## - Inverse variance method
## - Restricted maximum-likelihood estimator for tau^2
## - Q-Profile method for confidence interval of tau^2 and tau
## - Hartung-Knapp adjustment for random effects model (df = 13)
## - Fisher's z transformation of correlations
```

The test of subgroup differences between physical activity outcomes was possible between studies using active time per day or week (k = 5), MET-min/week (k = 4), or a score from a questionnaire (k = 3). We found statistical difference between these studies (p = 0.006), with only the studies using active time per day or week (r = -0.22; 95% CI: -0.30 to -0.14) and a score from a questionnaire (r = -0.27; 95% CI: -0.39 to -0.14) showing a statistically significant correlation.

```r
forest(PAout_subg,
            layout = "RevMan5",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1.0, 1.0),
            prediction = TRUE,
            fontsize = 11,
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)
```




```r
png(file = "PA outcome forestplot.png",
    width = 2800, height = 3200, res = 300)

forest(PAout_subg,
             layout = "RevMan5",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1.0, 1.0),
            prediction = TRUE,
            fontsize = 11,
```

```r
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)

dev.off()
```

```
## pdf
##   2
```

Subgroup analysis by apathy measure

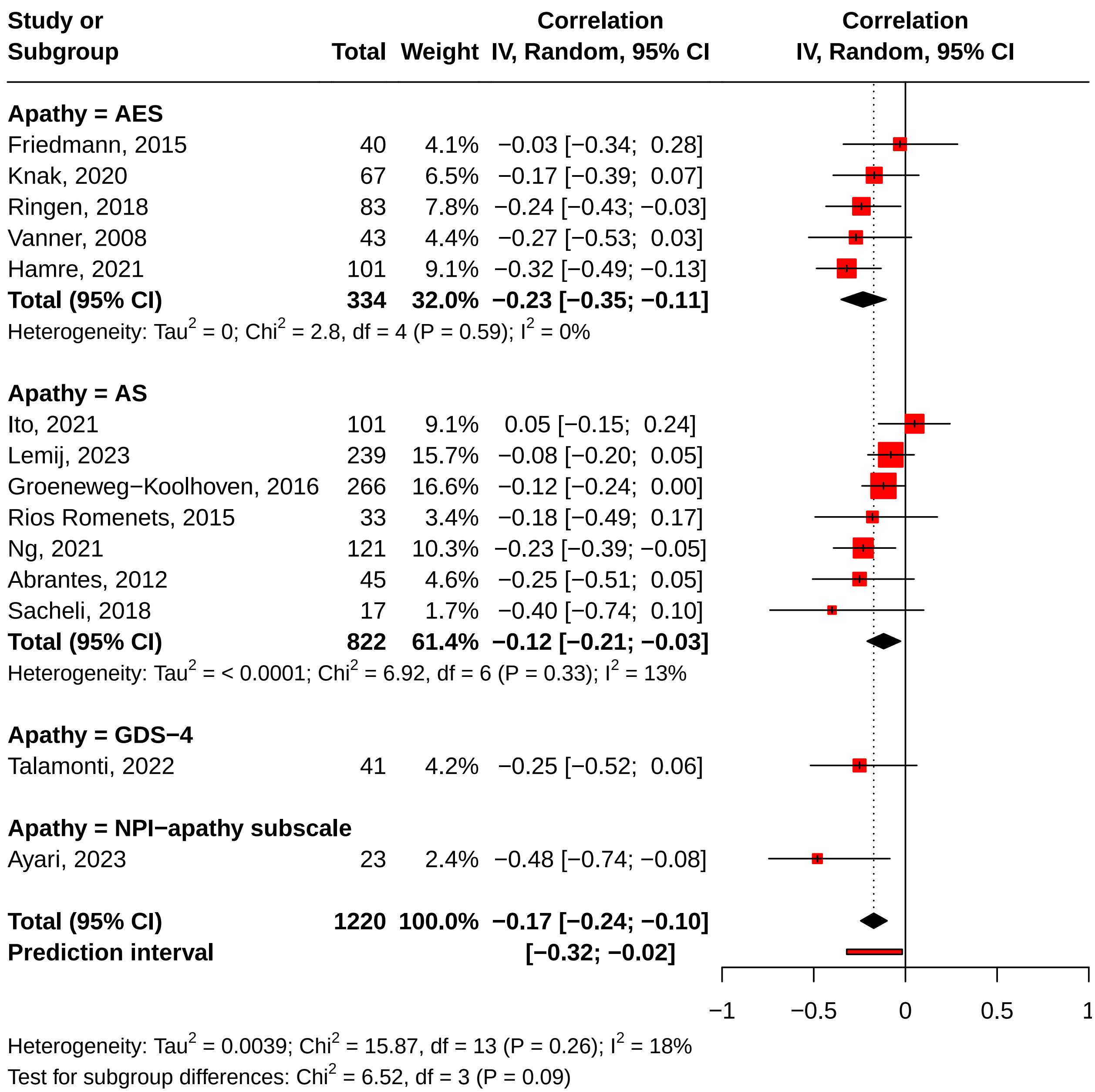
```r
apathy_r$Apathy <- as.factor(apathy_r$Apathy)

apathy_subg <- update(m.cor,
            subgroup = Apathy,
            tau.common = FALSE)
apathy_subg
```

```
## Review:     Apathy and physical activity behaviour
##
## Number of studies: k = 14
## Number of observations: o = 1220
##
##                         COR            95%-CI     t p-value
## Random effects model -0.1728 [-0.2437; -0.1002] -5.09  0.0002
##
## Quantifying heterogeneity:
##  tau^2 = 0.0039 [0.0000; 0.0321]; tau = 0.0626 [0.0000; 0.1791]
##  I^2 = 18.1% [0.0%; 55.8%]; H = 1.11 [1.00; 1.50]
##
## Test of heterogeneity:
##      Q d.f. p-value
##  15.87   13  0.2560
##
## Results for subgroups (random effects model):
##                                k     COR            95%-CI   tau^2    tau    Q
## Apathy = AES                   5 -0.2316 [-0.3505; -0.1054]      0      0 2.80
## Apathy = AS                    7 -0.1186 [-0.2089; -0.0263] <0.0001 0.0005 6.92
## Apathy = GDS-4                 1 -0.2500 [-0.5178;  0.0625]     --     -- 0.00
## Apathy = NPI-apathy subscale   1 -0.4800 [-0.7448; -0.0845]     --     -- 0.00
##                                I^2
## Apathy = AES                  0.0%
## Apathy = AS                  13.3%
## Apathy = GDS-4                  --
## Apathy = NPI-apathy subscale    --
##
## Test for subgroup differences (random effects model):
##                    Q d.f. p-value
## Between groups 6.52    3  0.0890
##
## Details on meta-analytical method:
## - Inverse variance method
## - Restricted maximum-likelihood estimator for tau^2
## - Q-Profile method for confidence interval of tau^2 and tau
```

```
## - Hartung-Knapp adjustment for random effects model (df = 13)
## - Fisher's z transformation of correlations
```

The test of subgroup differences between apathy measures was possible between studies using the Apathy Scale (k = 7) and the Apathy Evaluation Scale (k = 5). We observed no evidence of a statistical difference between these measures (p = 0.09), with only both studies using the Apathy Scale (r = -0.12; 95% CI: -0.24 to -0.10) and the Apathy Evaluation Scale (r = -0.23; 95% CI: -0.35 to -0.11) showing a statistically significant correlation.

```r
forest(apathy_subg,
            layout = "Revman5",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1, 1),
            prediction = TRUE,
            fontsize = 11,
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)
```




```r
png(file = "Apathy measure forestplot.png",
    width = 2800, height = 3200, res = 300)

forest(apathy_subg,
            layout = "Revman5",
            sortvar = -TE,
            common = FALSE,
            xlim = c(-1, 1),
            prediction = TRUE,
            fontsize = 11,
            fs.hetstat = 10,
            col.subgroup = 'black',
            addrows.below.overall = 2)
```

```r
dev.off()
```

```
## pdf
##   2
```

Meta-analysis: meta-regression

Meta-regression by age

```r
m.cor.reg.age <- metareg(m.cor, ~Age)
```

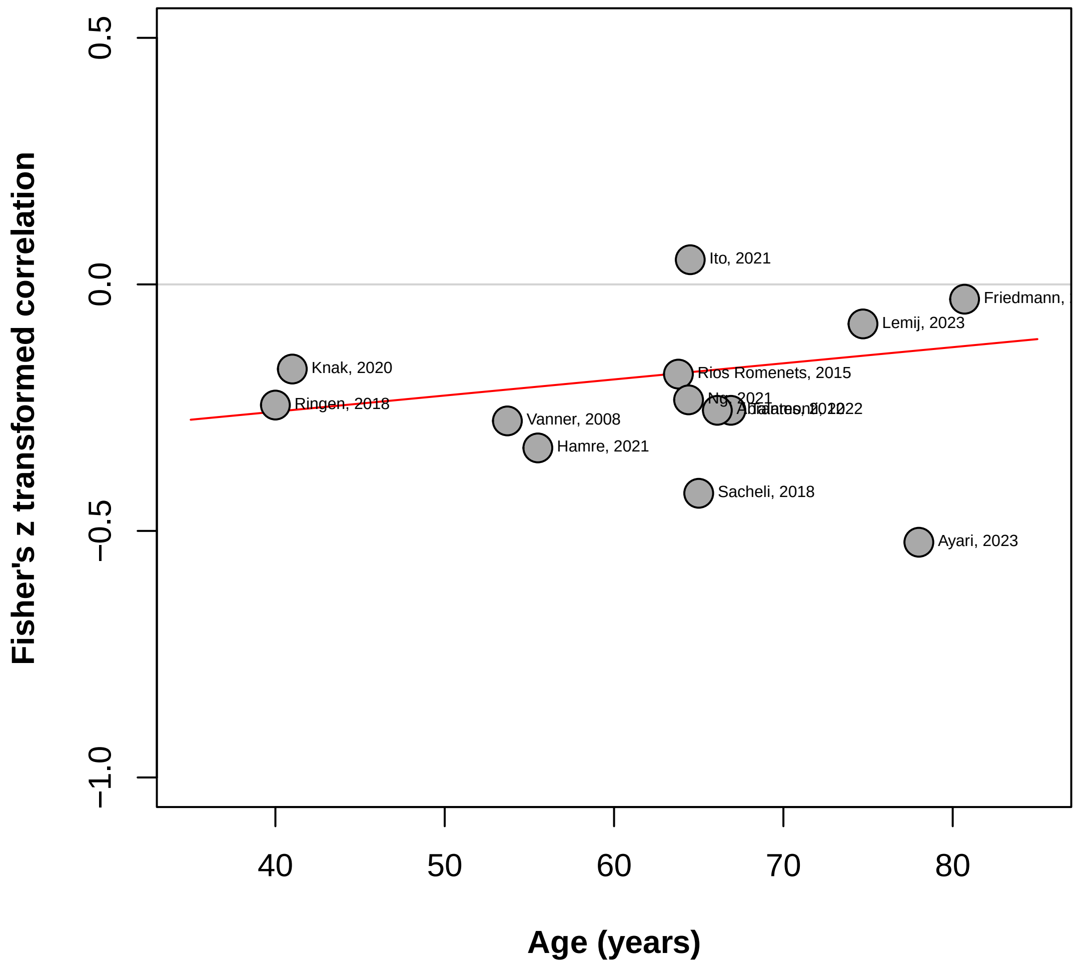
```
## Warning: 1 study with NAs omitted from model fitting.
```

```r
m.cor.reg.age
```

```
##
## Mixed-Effects Model (k = 13; tau^2 estimator: REML)
##
## tau^2 (estimated amount of residual heterogeneity):     0.0043 (SE = 0.0082)
## tau (square root of estimated tau^2 value):             0.0654
## I^2 (residual heterogeneity / unaccounted variability): 21.16%
## H^2 (unaccounted variability / sampling variability):   1.27
## R^2 (amount of heterogeneity accounted for):            26.89%
##
## Test for Residual Heterogeneity:
## QE(df = 11) = 13.2231, p-val = 0.2790
##
## Test of Moderators (coefficient 2):
## F(df1 = 1, df2 = 11) = 1.0733, p-val = 0.3224
##
## Model Results:
##
##          estimate      se     tval  df    pval    ci.lb   ci.ub
## intrcpt   -0.3889  0.1996  -1.9487  11  0.0773  -0.8282  0.0503  .
## Age        0.0033  0.0032   1.0360  11  0.3224  -0.0037  0.0102
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Age statistically influenced the correlation values of the meta-analysis studies (k = 9; p = 0.0009).

```r
Age.bubble <- bubble(m.cor.reg.age,
                     xlim = c(35, 85),
                     ylim = c(-1.0, 0.5),
                     xlab = 'Age (years)',
                     font.lab = 2,
                     studlab = TRUE,
                     cex = 2,
                     cex.studlab = 0.5,
                     pos.studlab = 4,
                     offset = 0.5,
                     col.line = 'red')
```




```
Age.bubble
```

```
## NULL
```

```
png(file = "Bubble plot for meta-regression by age.png",
    width = 2500, height = 2500, res = 300)

Age.bubble
```

```
## NULL
```

```
dev.off()
```

```
## pdf
##   2
```

Meta-regression by proportion of women

```
m.cor.reg.women <- metareg(m.cor, ~Prop_women)
```

```
## Warning: 1 study with NAs omitted from model fitting.
```

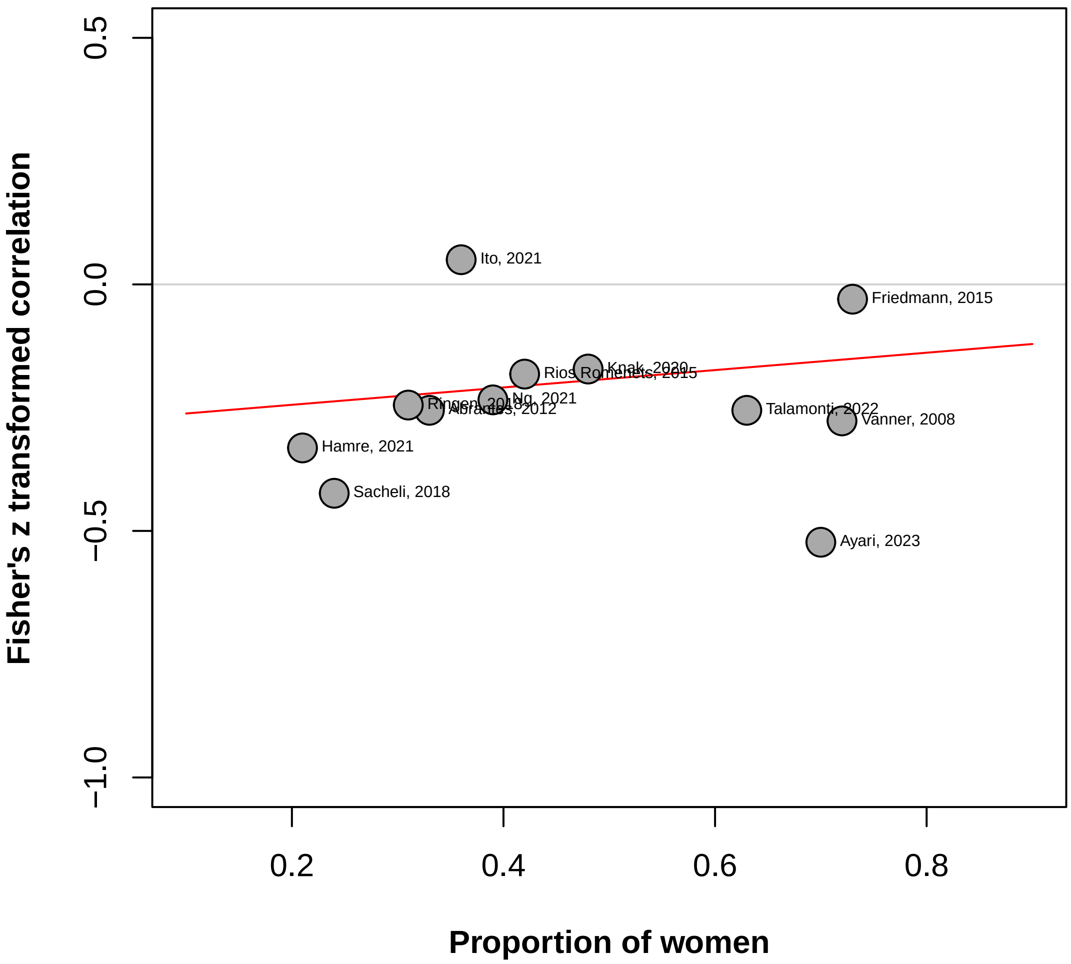
```
m.cor.reg.women
```

```
##
## Mixed-Effects Model (k = 13; tau^2 estimator: REML)
```

```
##
## tau^2 (estimated amount of residual heterogeneity):     0.0044 (SE = 0.0089)
## tau (square root of estimated tau^2 value):             0.0660
## I^2 (residual heterogeneity / unaccounted variability): 19.89%
## H^2 (unaccounted variability / sampling variability):   1.25
## R^2 (amount of heterogeneity accounted for):            25.53%
##
## Test for Residual Heterogeneity:
## QE(df = 11) = 12.6242, p-val = 0.3186
##
## Test of Moderators (coefficient 2):
## F(df1 = 1, df2 = 11) = 1.5838, p-val = 0.2343
##
## Model Results:
##
##             estimate      se     tval  df    pval    ci.lb    ci.ub
## intrcpt      -0.2795  0.0831  -3.3630  11  0.0063  -0.4624  -0.0966  **
## Prop_women    0.1761  0.1399   1.2585  11  0.2343  -0.1319   0.4841
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conversely, the proportion of women (k = 9) did not statistically influence the meta-analysis studies' correlation values.

```r
Propwomen.bubble <- bubble(m.cor.reg.women,
       xlim = c(0.1, 0.9),
       ylim = c(-1, 0.5),
       xlab = 'Proportion of women',
       font.lab = 2,
       studlab = TRUE,
       cex = 2,
       cex.studlab = 0.5,
       pos.studlab = 4,
       offset = 0.5,
       col.line = 'red')
```




```r
Propwomen.bubble
```

```
## NULL
```

```r
png(file = "Bubble plot for meta-regression by proportion of women.png",
    width = 2500, height = 2500, res = 300)

Propwomen.bubble
```

```
## NULL
```

```r
dev.off()
```

```
## pdf
##   2
```

Sensitivity analysis: meta-regression by axis score

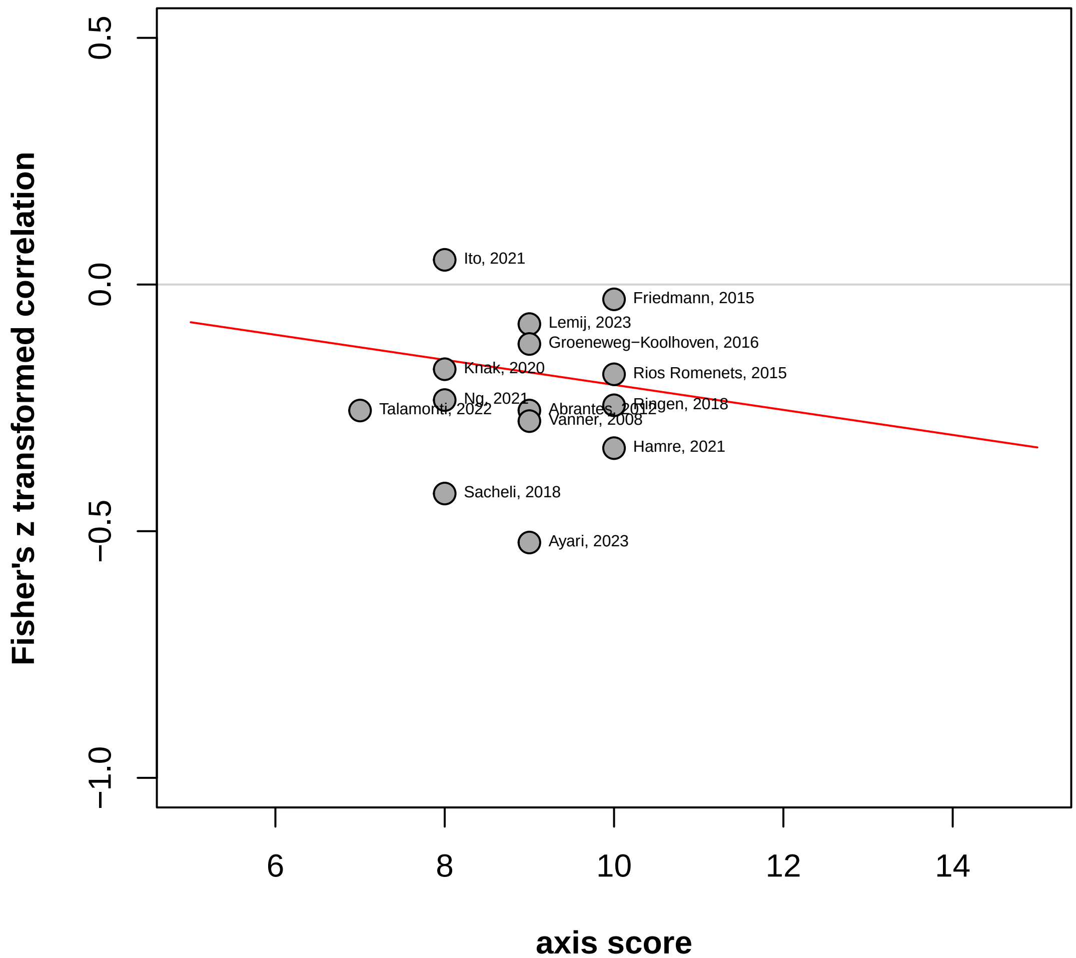
```r
m.cor.reg.axis <- metareg(m.cor, ~ Q_score)
m.cor.reg.axis
```

```
##
## Mixed-Effects Model (k = 14; tau^2 estimator: REML)
##
```

```
## tau^2 (estimated amount of residual heterogeneity):     0.0041 (SE = 0.0066)
## tau (square root of estimated tau^2 value):             0.0643
## I^2 (residual heterogeneity / unaccounted variability): 24.71%
## H^2 (unaccounted variability / sampling variability):   1.33
## R^2 (amount of heterogeneity accounted for):            0.00%
##
## Test for Residual Heterogeneity:
## QE(df = 12) = 15.2928, p-val = 0.2258
##
## Test of Moderators (coefficient 2):
## F(df1 = 1, df2 = 12) = 0.3523, p-val = 0.5638
##
## Model Results:
##
##          estimate      se     tval  df    pval    ci.lb   ci.ub
## intrcpt    0.0504  0.3814   0.1320  12  0.8971  -0.7806  0.8813
## Q_score   -0.0254  0.0428  -0.5935  12  0.5638  -0.1185  0.0678
##
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The meta-regression by quality score based on the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (k = 9) showed that a study's quality did not influence correlation values (p = 0.813).

```
Axis.bubble <- bubble(m.cor.reg.axis,
                xlim = c(5, 15),
                ylim = c(-1.0, 0.5),
                xlab = 'axis score',
                studlab = TRUE,
                font.lab = 2,
                cex = 1.5,
                cex.studlab = 0.5,
                pos.studlab = 4,
                offset = 0.5,
                col.line = 'red')
```

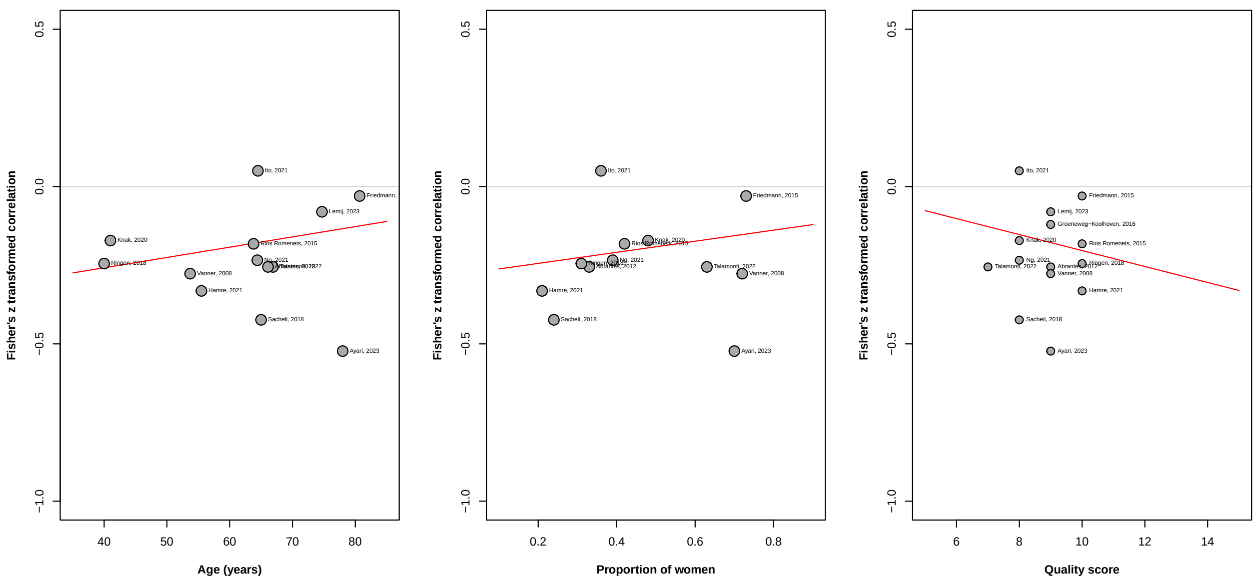



```
Axis.bubble
```

```
## NULL
```

```
parameter <- par(mfrow=c(1,3))

parameter <- bubble(m.cor.reg.age,
                    xlim = c(35, 85),
                    ylim = c(-1, 0.5),
                    xlab = 'Age (years)',
                    font.lab = 2,
                    studlab = TRUE,
                    cex = 2,
                    cex.studlab = 0.5,
                    pos.studlab = 4,
                    offset = 0.5,
                    col.line = 'red')

parameter <- bubble(m.cor.reg.women,
                    xlim = c(0.1, 0.9),
                    ylim = c(-1.0, 0.5),
                    xlab = 'Proportion of women',
                    font.lab = 2,
                    studlab = TRUE,
```

```
                   cex = 2,
                   cex.studlab = 0.5,
                   pos.studlab = 4,
                   offset = 0.5,
                   col.line = 'red')

parameter <- bubble(m.cor.reg.axis,
                  xlim = c(5, 15),
                  ylim = c(-1.0, 0.5),
                  xlab = 'Quality score',
                  studlab = TRUE,
                  font.lab = 2,
                  cex = 1.5,
                  cex.studlab = 0.5,
                  pos.studlab = 4,
                  offset = 0.5,
                  col.line = 'red')
```



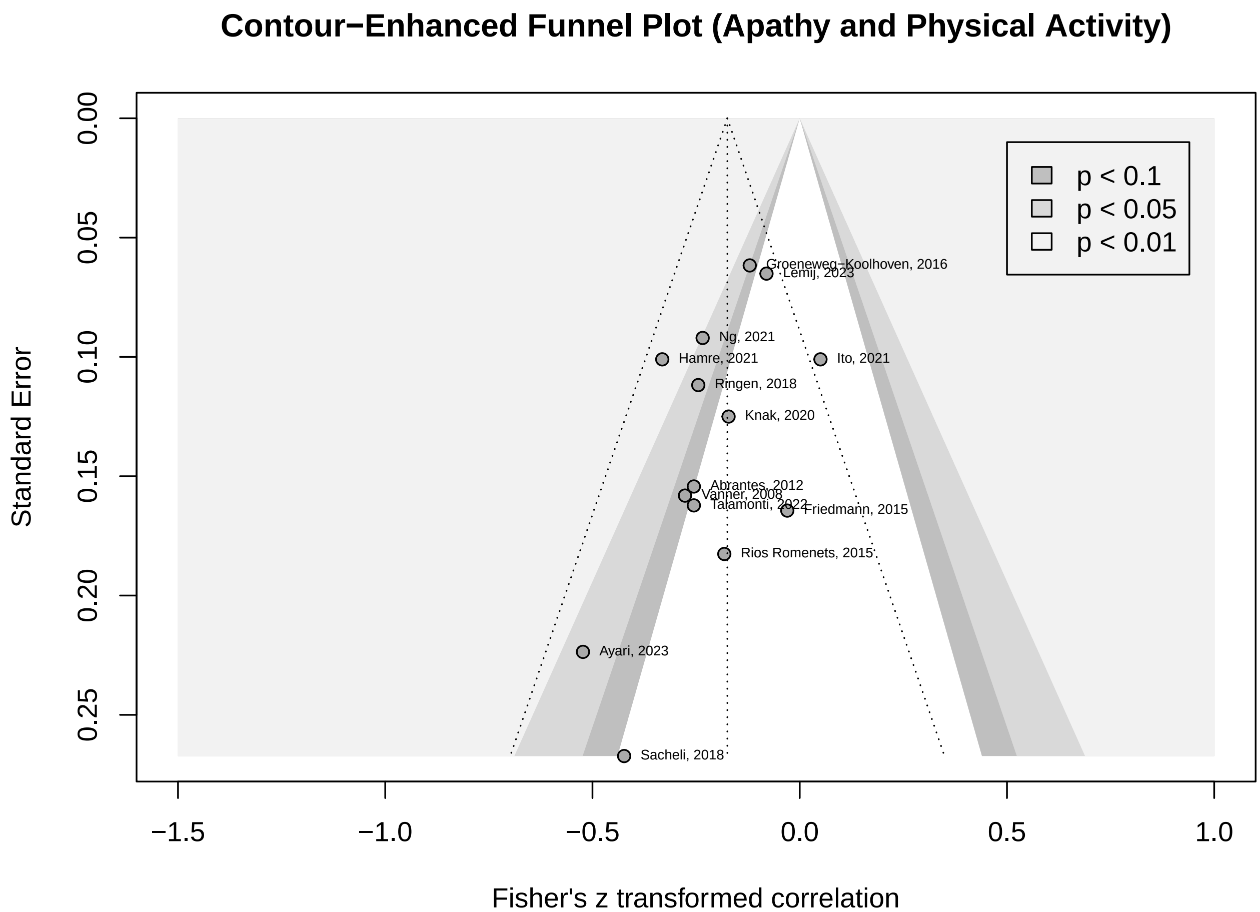
Publication bias analysis

Small-study effects

Funnel plot

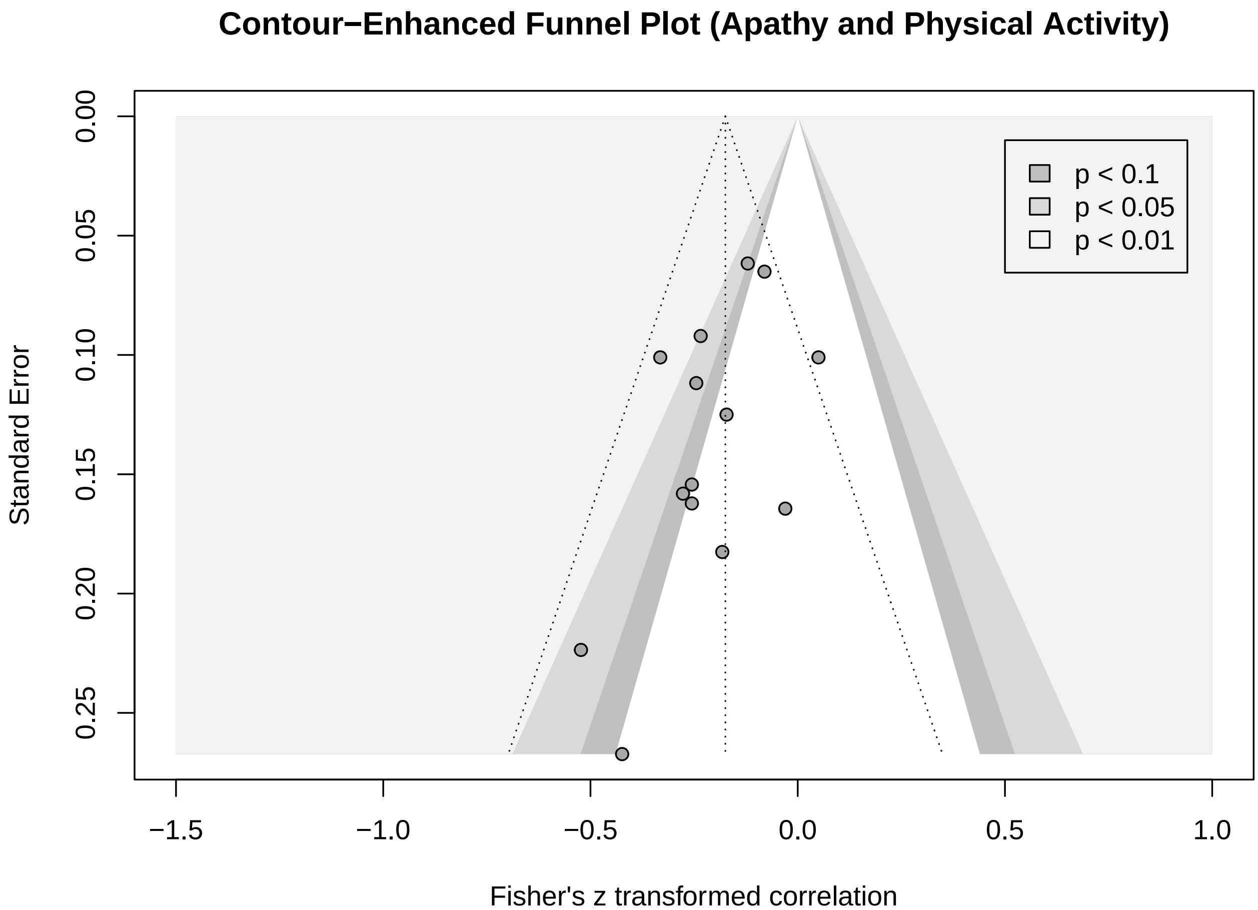
```
# Define fill colors for contour
col.contour = c("gray75", "gray85", "gray95")

# Funnel plot
funnel(m.cor,
       xlim = c(-1.5, 1),
       contour = c(0.9, 0.95, 0.99),
       col.contour = col.contour,
       studlab = TRUE,
       cex = 1,
       cex.studlab = 0.5,
```

```r
       pos.studlab = 4,
       offset = 0.5)

# legend
legend(x =0.5, y = 0.01,
       legend = c("p < 0.1", "p < 0.05", "p < 0.01"),
       fill = col.contour)

# title
title("Contour-Enhanced Funnel Plot (Apathy and Physical Activity)")
```

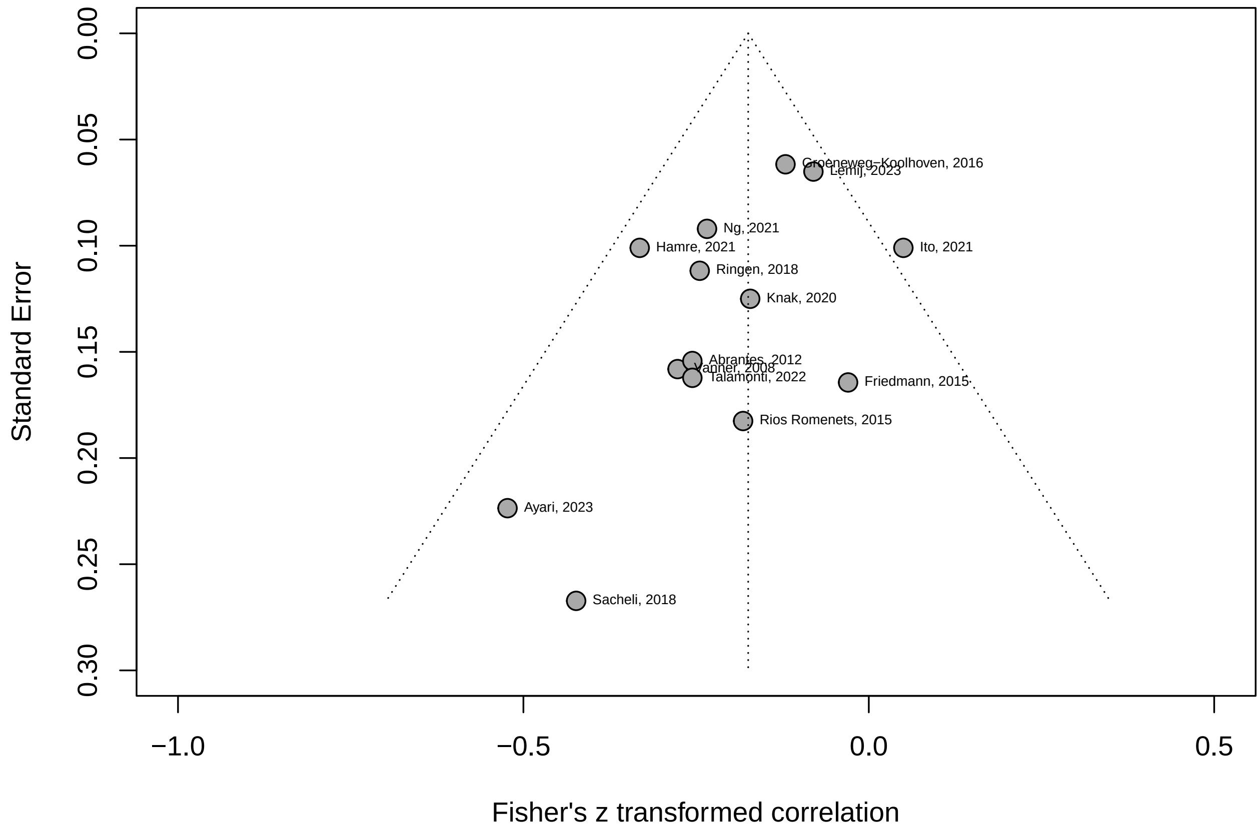



```r
# Define fill colors for contour
col.contour = c("gray75", "gray85", "gray95")

# Funnel plot
funnel(m.cor,
       xlim = c(-1.5, 1),
       contour = c(0.9, 0.95, 0.99),
       studlab = FALSE,
       cex = 1,
       cex.studlab = 0.5,
       pos.studlab = 4,
       offset = 0.5,
       col.contour = col.contour)
```

```r
# legend
legend(x =0.5, y = 0.01,
       legend = c("p < 0.1", "p < 0.05", "p < 0.01"),
       fill = col.contour)

# title
title("Contour-Enhanced Funnel Plot (Apathy and Physical Activity)")
```




```r
# Produce funnel plot
funnel(m.cor,
            xlim = c(-1, 0.5),
            ylim = c(0.3, 0.0),
            studlab = TRUE,
            cex = 1.5,
            cex.studlab = 0.5,
            pos.studlab = 4,
            offset = 0.5)
```




```r
png(file = "Funnel Plot.png", width = 2100, height = 1500, res = 300)

# Define fill colors for contour
col.contour = c("gray75", "gray85", "gray95")

# Funnel plot
funnel(m.cor,
       xlim = c(-1.5, 1),
       contour = c(0.9, 0.95, 0.99),
       col.contour = col.contour,
       studlab = TRUE,
       cex = 1,
       cex.studlab = 0.5,
       pos.studlab = 4,
       offset = 0.5)

# legend
legend(x =0.5, y = 0.01,
       legend = c("p < 0.1", "p < 0.05", "p < 0.01"),
       fill = col.contour)

# title
title("Contour-Enhanced Funnel Plot (Apathy and Physical Activity)")

dev.off()
```

```
## pdf
##   2
```

Egger's test

```r
metabias(m.cor, method.bias = "linreg", k.min = 9)
```

```
## Review:     Apathy and physical activity behaviour
##
## Linear regression test of funnel plot asymmetry
##
## Test result: t = -2.10, df = 12, p-value = 0.0580
##
## Sample estimates:
##     bias se.bias intercept se.intercept
##  -1.3921  0.6644   -0.0227       0.0724
##
## Details:
## - multiplicative residual heterogeneity variance (tau^2 = 0.9685)
## - predictor: standard error
## - weight:    inverse variance
## - reference: Egger et al. (1997), BMJ
```

```r
eggers.test(m.cor)
```

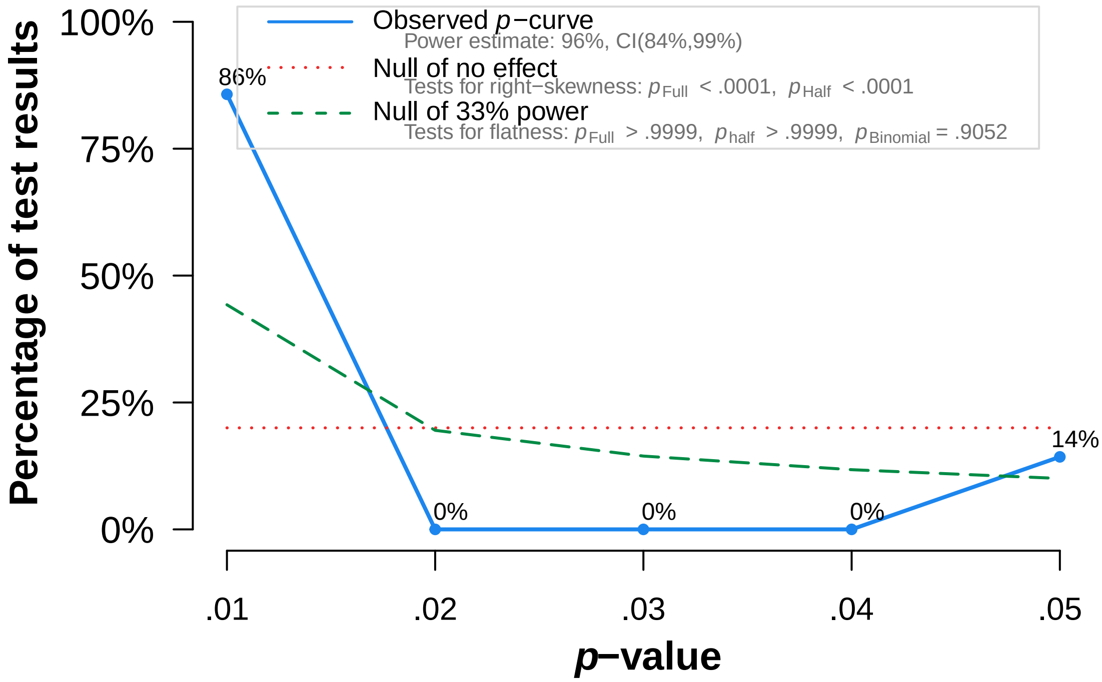
```
## Eggers' test of the intercept
## =============================
##
##  intercept       95% CI      t          p
##     -1.392 -2.69 - -0.09 -2.095 0.05802661
##
## Eggers' test does not indicate the presence of funnel plot asymmetry.
```

Egger's regression test does not indicate the presence of funnel plot asymmetry (b = -1.39, 95% CI: -2.69 to -0.09, p = 0.058), which suggests that publication bias is unlikely to influence the effect sizes observed in the main meta-analysis.

Pcurve analysis

Standard errors of the correlation values were calculated using the formula: sqrt((1 - correlation_coefficient^2) / (sample_size - 2))

```r
p_curve_data = data.frame("studlab" = c(paste("Study_", 1:21, sep = "")),
                 "TE" = c(-0.27, -0.057, -0.37, -0.23, -0.25, -0.18, -0.03, -0.25,
                          -0.048, -0.12, -0.32, 0.05, -0.17, -0.08, -0.49, -0.39,
                          -0.15, 0.01, -0.11, -0.71, -0.31),

                 "seTE" = c(0.150373518685809, 0.257779104402717, 0.103225750448013,
                            0.089212238675037,0.147656105804655, 0.176671738616584,
                            0.162148405058939, 0.155043418, 0.217966358,
                            0.0611010092660779, 0.095219046, 0.100378073, 0.122229293,
                            0.064748784, 0.085479417225615, 0.090293325, 0.108522387,
                            0.109758772, 0.109098165, 0.109977825, 0.170757326))

pcurve(p_curve_data)
```



Note: The observed p−curve includes 7 statistically significant (p < .05) results, of which 6 are p < .025.
There were 14 additional results entered but excluded from p−curve because they were p > .05.

```
## P-curve analysis
##  -----------------------
## - Total number of provided studies: k = 21
## - Total number of p<0.05 studies included into the analysis: k = 7 (33.33%)
## - Total number of studies with p<0.025: k = 6 (28.57%)
##
## Results
##  -----------------------
##                      pBinomial  zFull pFull  zHalf pHalf
## Right-skewness test      0.062 -6.607     0 -7.453     0
## Flatness test            0.905  4.321     1  6.564     1
## Note: p-values of 0 or 1 correspond to p<0.001 and p>0.999, respectively.
## Power Estimate: 96% (84.1%-99%)
##
## Evidential value
##  -----------------------
## - Evidential value present: yes
## - Evidential value absent/inadequate: no
```

The 21 studies reporting a correlation value (Pearson's r or Spearman's rho) were provided to the p-curve analysis. The observed p-curve includes seven (33.3%) statistically significant results ($p < 0.05$), with the six of them being $p < 0.025$ (Figure 4). The other results were excluded because they had a $p > 0.05$. The p-value of the right-skewness test was < 0.001 for both the half curve and the full curve, suggesting that evidential value was present, i.e., that the effect we estimated is not spurious; an artifact caused by selective reporting (e.g., p-hacking) in the literature.

References

- Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed.; 1988.

- Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315(7109):629-634. https://doi.org/10.1136/bmj.315.7109.62

- Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21(11):1539-1558. https://doi.org/10.1002/sim.1186

- Knapp G, Hartung J. Improved tests for a random effects meta-regression with a single covariate. Stat Med. 2003;22(17):2693-2710. https://doi.org/10.1002/sim.1482

- R Core Team. R: A language and environment for statistical computing [Computer software]. Version 4.3.1. Vienna, Austria: Foundation for Statistical Computing; 2023. https://www.r-project.org
- Schwarzer G. Meta: General package for meta-analysis [R package]. Version 6.5-0; 2023a. https://cran.r-project.org/web/packages/meta/meta.pdf
- Schwarzer G, Carpenter RJ, Rücker G. Metasens: Advanced statistical methods to model and adjust for bias in meta-analysis [R package]. Version 1.5-2; 2023b. https://cran.r-project.org/web/packages/metasens/metasens.pdf

- Simonsohn U, Nelson LD, Simmons JP. P-curve: A key to the file-drawer. J Exp Psychol Gen. 2014;143(2):534-547. http://doi.org/10.1037/a0033242

- Viechtbauer W. Bias and efficiency of meta-analytic variance estimators in the random-effects model. J Educ Behav Stat. 2005;30(3):261-293. https://doi.org/10.3102/10769986030003261

- Viechtbauer W. Conducting meta-analyses in R with the metafor package. J Stat Softw. 2010;36(3):1-48. https://doi.org/10.18637/jss.v036.i03

- Viechtbauer W. Metafor: Meta-analysis package for R [R package]. Version 4.2-0; 2023. https://cran.r-pro-ject.org/web/packages/metafor/metafor.pdf

- Viechtbauer, “W. (2023). Metafor: Meta-Analysis Package for R (Version 4.2-0) [R pakage]. https://cran.r-project.org/web/packages/metafor/metafor.pdf