AIMS Neuroscience

AIMS Neuroscience, 13(4): 667–691.
DOI: 10.3934/Neuroscience.2026031
Received: 21 July 2026
Revised: 07 October 2026
Accepted: 27 October 2026
Published: 12 November 2026

https://www.aimspress.com/journal/neuroscience

Review

Outcomes of bilateral repetitive transcranial magnetic stimulation application after stroke on upper extremity functional status: A systematic review and meta-analysis

Michalis Kodounis[1,2,*], Dilara Onan[2,3], Damla Hazal Sucu[4], Raffaele Ornello[2], Simona Sacco[2], Dimos Dimitrios Mitsikostas[1], Efthimios Dardiotis[5] and Vasileios Siokas[5]

[1] First Neurology Department, Eginitio Hospital, School of Medicine, National & Kapodistrian University of Athens, Athens, Greece
[2] Department of Biotechnological and Applied Clinical Sciences, University of L'Aquila, L'Aquila, Italy
[3] Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Yozgat Bozok University, Yozgat, Türkiye
[4] Department of Biostatistics and Medical Informatics, Mersin University School of Medicine, Mersin, Türkiye
[5] Department of Neurology, University Hospital of Larissa, School of Medicine, University of Thessaly, Larissa, Greece

* **Correspondence:** Email: kodounis@gmail.com; Tel: +30 697 3600069.

Supplementary

Supplement 1. PRISMA Checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1, 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2, 3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	3, 4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	4, 5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	7
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	7

Section and Topic	Item #	Checklist item	Location where item is reported
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	5
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	7
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	7
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	7
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	7
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	7
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	7
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	7
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	7, 8
Study characteristics	17	Cite each included study and present its characteristics.	9,10,11,12,13

Section and Topic	Item #	Checklist item	Location where item is reported
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	13
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	14, 15
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	14, 15
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	14, 15, 16
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	14, 15, 16
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	14, 15, 16
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	14, 15, 16
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	14, 15, 16
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	17, 18, 19, 20
	23b	Discuss any limitations of the evidence included in the review.	20
	23c	Discuss any limitations of the review processes used.	20
	23d	Discuss implications of the results for practice, policy, and future research.	21, 22, 23
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	4

Section and Topic	Item #	Checklist item	Location where item is reported
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	23
Competing interests	26	Declare any competing interests of review authors.	23
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	24

Note: From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/.

Supplement 2. Search Strategy.

PubMed:

(stroke[MeSH Terms] OR stroke[Title/Abstract] OR cerebral infarction[Title/Abstract]) AND (upper limb[Title/Abstract] OR lower limb[Title/Abstract] OR motor recovery[Title/Abstract] OR motor function[Title/Abstract] OR hemiplegia[Title/Abstract] OR Fugl-Meyer[Title/Abstract]) AND (repetitive transcranial magnetic stimulation[MeSH Terms] OR repetitive transcranial magnetic stimulation[Title/Abstract] OR rTMS[Title/Abstract] OR transcranial magnetic stimulation[Title/Abstract] OR theta burst stimulation[Title/Abstract] OR iTBS[Title/Abstract]) AND (bilateral[Title/Abstract] OR interhemispheric[Title/Abstract] OR contralesional[Title/Abstract] OR ipsilesional[Title/Abstract] OR unaffected hemisphere[Title/Abstract] OR affected hemisphere[Title/Abstract]) AND (coupling[Title/Abstract] OR combined[Title/Abstract] OR sequential[Title/Abstract] OR conditioning[Title/Abstract] OR low frequency[Title/Abstract] OR high frequency[Title/Abstract] OR inhibitory[Title/Abstract] OR facilitatory[Title/Abstract] OR 1 Hz[Title/Abstract])

Web of Science:

TS= ((stroke OR stroke OR cerebral infarction) AND (upper limb OR lower limb OR motor recovery OR motor function OR hemiplegia OR Fugl-Meyer) AND (repetitive transcranial magnetic stimulation OR repetitive transcranial magnetic stimulation OR rTMS OR transcranial magnetic stimulation OR theta burst stimulation OR iTBS) AND (bilateral OR interhemispheric OR contralesional OR ipsilesional OR unaffected hemisphere OR affected hemisphere) AND (coupling OR combined OR sequential OR conditioning OR low frequency OR high frequency OR inhibitory OR facilitatory OR 1 Hz))

Scopus:

((stroke OR stroke OR cerebral infarction) AND (upper limb OR lower limb OR motor recovery OR motor function OR hemiplegia OR Fugl-Meyer) AND (repetitive transcranial magnetic stimulation OR repetitive transcranial magnetic stimulation OR rTMS OR transcranial magnetic stimulation OR theta burst stimulation OR iTBS) AND (bilateral OR interhemispheric OR contralesional OR ipsilesional OR unaffected hemisphere OR affected hemisphere) AND (coupling OR combined OR sequential OR conditioning OR low frequency OR high frequency OR inhibitory OR facilitatory OR 1 Hz))

Cochrane Central Register of Controlled Trials:

(stroke OR "cerebral infarction") AND ("transcranial magnetic stimulation" OR rTMS OR "theta burst stimulation" OR iTBS) AND (bilateral OR interhemispheric OR contralesional OR ipsilesional)

Supplement 3. R Analysis Code.

```
library(metafor)
library(dplyr)

# ========================
# 1. DATA
# ========================
```

```
dat <- data.frame(
  study = c("Long et al. 2018", "Chen1 et al. 2021", "Sung et al. 2013",
            "Abdelkader et al. 2024", "Meng et al. 2020", "Chen2 et al. 2021"),

  n_bilateral = c(21, 22, 15, 15, 10, 25),
  mean_bilateral_pre = c(34.90, 21.80, 28.00, 45.07, NA, 18.60),
  sd_bilateral_pre = c(3.79, 15.50, 12.20, 11.59, NA, 2.83),
  mean_bilateral_post = c(47.57, 53.60, 30.90, 56.20, NA, 57.04),
  sd_bilateral_post = c(2.94, 15.40, 10.30, 6.84, NA, 2.98),

  n_sham = c(20, 22, 14, 10, 8, 25),
  mean_sham_pre = c(34.95, 19.50, 27.30, 46.20, NA, 16.88),
  sd_sham_pre = c(3.25, 18.10, 11.60, 12.67, NA, 2.83),
  mean_sham_post = c(36.00, 25.80, 28.70, 48.60, NA, 21.76),
  sd_sham_post = c(3.27, 21.60, 13.10, 10.57, NA, 2.90)
)

dat$study <- factor(
  dat$study,
  levels = c("Sung et al. 2013", "Long et al. 2018", "Meng et al. 2020",
             "Chen1 et al. 2021", "Chen2 et al. 2021", "Abdelkader et al. 2024")
)

dat <- arrange(dat, study)

# ========================
# 2. CHANGE SCORES
# ========================

r <- 0.60

dat <- dat %>%
  mutate(
    calc_change_bilat = mean_bilateral_post - mean_bilateral_pre,
    calc_change_sham  = mean_sham_post - mean_sham_pre,

    calc_sd_bilat = sqrt(sd_bilateral_pre^2 + sd_bilateral_post^2 -
                           2 * r * sd_bilateral_pre * sd_bilateral_post),

    calc_sd_sham = sqrt(sd_sham_pre^2 + sd_sham_post^2 -
                          2 * r * sd_sham_pre * sd_sham_post),

    change_bilat = ifelse(study == "Meng et al. 2020", 8.7, calc_change_bilat),
    change_sham  = ifelse(study == "Meng et al. 2020", 3.0, calc_change_sham),
```

```
    sd_change_bilat = ifelse(study == "Meng et al. 2020", 6.2, calc_sd_bilat),
    sd_change_sham  = ifelse(study == "Meng et al. 2020", 1.9, calc_sd_sham),

    data_source = ifelse(
      study == "Meng et al. 2020",
      "Directly reported change score",
      "Change SD reconstructed"
    )
  )

# ========================
# 3. EFFECT SIZES
# ========================

es <- escalc(
  measure = "MD",
  m1i = change_bilat, sd1i = sd_change_bilat, n1i = n_bilateral,
  m2i = change_sham,  sd2i = sd_change_sham,  n2i = n_sham,
  data = dat
)

# ========================
# 4. MAIN META-ANALYSIS
# ========================

res_hk <- rma(yi, vi, data = es, method = "REML", test = "knha")
pred_hk <- predict(res_hk)

# ========================
# 5. STUDY-LEVEL RESULTS
# ========================

study_results <- data.frame(
  Study = as.character(dat$study),
  N_Bilateral = dat$n_bilateral,
  Change_Bilateral = dat$change_bilat,
  SD_Change_Bilateral = dat$sd_change_bilat,
  N_Sham = dat$n_sham,
  Change_Sham = dat$change_sham,
  SD_Change_Sham = dat$sd_change_sham,
  MD = es$yi,
  Variance = es$vi,
  SE = sqrt(es$vi),
```

```
  CI_Lower = es$yi - qnorm(0.975) * sqrt(es$vi),
  CI_Upper = es$yi + qnorm(0.975) * sqrt(es$vi),
  Weight = as.numeric(weights(res_hk)),
  Data_Source = dat$data_source
)

# ========================
# 6. LEAVE-ONE-OUT
# ========================

loo <- leave1out(res_hk)

# ========================
# 7. SENSITIVITY  r = 0.3–0.9
# Meng stays fixed
# ========================

r_values <- seq(0.3, 0.9, 0.1)

sensitivity_results <- do.call(rbind, lapply(r_values, function(rr) {

  tmp <- dat %>%
    mutate(
      sd_bilat_tmp = sqrt(sd_bilateral_pre^2 + sd_bilateral_post^2 -
                          2 * rr * sd_bilateral_pre * sd_bilateral_post),

      sd_sham_tmp = sqrt(sd_sham_pre^2 + sd_sham_post^2 -
                         2 * rr * sd_sham_pre * sd_sham_post),

      change_bilat_tmp = ifelse(study == "Meng et al. 2020", 8.7, calc_change_bilat),
      change_sham_tmp  = ifelse(study == "Meng et al. 2020", 3.0, calc_change_sham),

      sd_change_bilat_tmp = ifelse(study == "Meng et al. 2020", 6.2, sd_bilat_tmp),
      sd_change_sham_tmp  = ifelse(study == "Meng et al. 2020", 1.9, sd_sham_tmp)
    )

  es_tmp <- escalc(
    measure = "MD",
    m1i = change_bilat_tmp, sd1i = sd_change_bilat_tmp, n1i = n_bilateral,
    m2i = change_sham_tmp,  sd2i = sd_change_sham_tmp,  n2i = n_sham,
    data = tmp
  )

  res_tmp <- rma(yi, vi, data = es_tmp, method = "REML", test = "knha")
```

```
  pred_tmp <- predict(res_tmp)

  data.frame(
    r = rr,
    MD = as.numeric(res_tmp$b),
    CI_Lower = res_tmp$ci.lb,
    CI_Upper = res_tmp$ci.ub,
    p = res_tmp$pval,
    tau2 = res_tmp$tau2,
    I2 = res_tmp$I2,
    PI_Lower = pred_tmp$pi.lb,
    PI_Upper = pred_tmp$pi.ub
  )
}))

# ========================
# 8. SUMMARY
# ========================

analysis_summary <- data.frame(
  k = res_hk$k,
  Pooled_MD = as.numeric(res_hk$b),
  CI_Lower = res_hk$ci.lb,
  CI_Upper = res_hk$ci.ub,
  p = res_hk$pval,
  tau2 = res_hk$tau2,
  tau = sqrt(res_hk$tau2),
  I2 = res_hk$I2,
  Q = res_hk$QE,
  Q_p = res_hk$QEp,
  PI_Lower = pred_hk$pi.lb,
  PI_Upper = pred_hk$pi.ub,
  LOO_Min = min(loo$estimate),
  LOO_Max = max(loo$estimate),
  Sensitivity_MD_Min = min(sensitivity_results$MD),
  Sensitivity_MD_Max = max(sensitivity_results$MD)
)

# ========================
# 9. PRINT EVERYTHING
# ========================

summary(res_hk)
study_results
```

```
loo
sensitivity_results
analysis_summary

# ========================
# FIGURE 3 - CLEAN FOREST PLOT
# ========================

graphics.off()

PI_low  <- as.numeric(pred_hk$pi.lb)
PI_high <- as.numeric(pred_hk$pi.ub)

study_rows <- 7:2

forest(
  res_hk,
  slab = as.character(dat$study),
  rows = study_rows,
  ylim = c(-3.5, 9),
  xlim = c(-42, 82),
  alim = c(-20, 50),
  at = seq(-20, 50, 10),
  annotate = FALSE,
  addfit = FALSE,
  header = FALSE,
  refline = 0,
  xlab = "Mean Difference in FMA-UE Change Score (Bilateral rTMS - Sham)",
  cex = 1,
  top = 1
)

text(-41, 8.4, "Study", pos = 4, font = 2)
text(57, 8.4, "Weight (%)", font = 2)
text(73, 8.4, "MD [95% CI]", font = 2)

text(57,study_rows,sprintf("%.1f%%", study_results$Weight),cex = 0.9)

text(73,study_rows,sprintf(
     "%.2f [%.2f, %.2f]",
     study_results$MD,
     study_results$CI_Lower,
     study_results$CI_Upper),cex = 0.9)
```

```
addpoly(
  res_hk,
  row = 0.35,
  annotate = FALSE,
  mlab = ""
)

text(
  -41,
  0.35,
  "Random-effects model",
  pos = 4,
  font = 2
)

text(
  57,
  0.35,
  "100.0%"
)

text(
  73,
  0.35,
  sprintf(
    "%.2f [%.2f, %.2f]",
    as.numeric(res_hk$b),
    res_hk$ci.lb,
    res_hk$ci.ub
  ),
  font = 2
)

segments(
  PI_low,
  -0.85,
  PI_high,
  -0.85,
  lwd = 2
)

segments(
  PI_low,
  -0.98,
```

```
  PI_low,
  -0.72,
  lwd = 2
)

segments(
  PI_high,
  -0.98,
  PI_high,
  -0.72,
  lwd = 2
)

text(
  -41,
  -0.85,
  "95% prediction interval",
  pos = 4
)

text(
  73,
  -0.85,
  sprintf(
    "[%.2f, %.2f]",
    PI_low,
    PI_high
  )
)

text(
  -41,
  -2,
  paste0(
    "Heterogeneity: τ² = ",
    sprintf("%.2f", res_hk$tau2),
    "; I² = ",
    sprintf("%.1f", res_hk$I2),
    "%"
  ),
  pos = 4
)

text(
```

```
  -41,
  -2.65,
  "Random-effects model: REML estimation with Hartung-Knapp adjustment",
  pos = 4,
  cex = 0.8
)
# NA: Not Available (Meng et al. did not report pre/post FMA-UE values; reported change scores were used)
```



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