publications

MDPI

Article

Practicing Meta-Analytics with Rectification

Ramalingam Shanmugam [1] and Karan P. Singh [2,*]

[1] School of Health Administration, Texas State University, San Marcos, TX 78666, USA; rs25@txstate.edu
[2] Department of Epidemiology and Biostatistics, The University of Texas at Tyler Health Science Center, School of Medicine, Tyler, TX 75708, USA
* Correspondence: karan.singh@uttyler.edu

Abstract: This article demonstrates the necessity of assessing homogeneity in meta-analyses using the Higgins method. The researchers realize the importance of assessing homogeneity in meta-analytic work. However, a significant issue with the Higgins method has been identified. In this article, we explain the nature of this problem and propose solutions to address it. Our narrative in this article is to point out the problem, analyze it, and present it well. A prerequisite to check the consistency of findings in comparable studies in meta-analyses is that the studies should be homogeneous, not heterogeneous. The Higgins I^2 score, a version of the Cochran Q value, is commonly used to assess heterogeneity. The Higgins score is an improvement in the Q value. However, there is a problem with Higgins score statistically. The Higgins score is supposed to follow a Chi-squared distribution, but it does not do so because the Chi-squared distribution becomes invalid once the Q score is less than the degrees of freedom. This problem was recently rectified using an alternative method (S^2 score). Using this method, we examined 14 published articles representing 133 datasets and observed that many studies declared homogeneous by the Higgins method were, in fact, heterogeneous. This article urges the research community to be cautious in making inferences using the Higgins method.

Keywords: homogeneity; Cochran's Q score; H^2 score; Higgin I^2 score; S^2 score; systematic reviews; meta-analytics

Academic Editor: Andrew Kirby

Received: 4 September 2024
Revised: 14 November 2024
Accepted: 25 November 2024
Published: 2 January 2025

Citation: Shanmugam, R., & Singh, K. P. (2025). Practicing Meta-Analytics with Rectification. *Publications*, *13*(1), 2. https://doi.org/10.3390/publications13010002

1. Introduction

Recently a refinement of the Higgins I^2 method has been published (Shanmugam et al., 2024). Earlier researchers used Higgins score to assess homogeneity among comparable studies in meta-analyses (Van den Noortgate & Onghena, 2024; Chowdhury et al., 2024). The Higgins method was initiated to strengthen the historic Cochrane approach. A good systematic reviews to compare studies in meta-analysis has been provided in the literature (Deeks et al., 2023). Meta-analysis compares the findings of comparable studies on a specific topic. Although systematic reviews and meta-analyses are related, they are not the same. Some meta-analyses can be part of systematic reviews (Greenwood et al., 2022). However, meta-analysis is considered a statistical methodology (Sahdra et al., 2024). Meta-analyses focus on odds or risk in comparisons using "effect size." The effect size (ES) is a standardized difference expressed in terms of proportions, averages, or correlation coefficients (Sahdra et al., 2024). Models play a significant role in composing ESs. There are fixed, random, or mixed-effect types in meta-analysis. In all these, homogeneity (the opposite of heterogeneity) among the studies is a necessity. The classical Cochran Q statistic captures heterogeneity in studies utilizing the likelihood ratios (LR) (Deeks et al., 2023). An advantage of the Q test is its ability to compare LR. However, the Q test is a traditional approach to assessing heterogeneity in comparable studies in meta-analyses, but it has low statistical power. A disadvantage of the Q test is its lack of intuitive interpretation for clinical professionals. Additionally, the Q test indicates only the presence or absence of heterogeneity, not its level. The Higgins score is an improved version of the Q test. Another version of the Cochran score is $H^2 = \frac{Q}{df}$ where df is the number of studies minus one and the H^2 is not popularized as the Higgins score. The relationship between the H^2 and the Higgins score I^2 is that $I^2 = \left(\frac{H^2-1}{H^2}\right)100\%$. Consequently, we pursue only the Higgins score further in this article. However, we could rewrite the relationship as $I^2 = \frac{E(Q)-(1+df)}{E(Q)}$. As a refinement, the Higgins score I^2 with improved statistical power was introduced for applied professionals. However, a disadvantage of the Higgins approach is its subjective rule of thumb. That is, when the Higgins score is less than 40%, the collection of comparable studies is considered to have unimportant heterogeneity. When the Higgins score is between 40% and 60%, the studies are considered to have moderate heterogeneity. When the Higgins score is above 60% but less than 100%, the heterogeneity among the chosen studies is substantially high (Deeks et al., 2023). The preamble for comparing the consistency of studies in meta-analyses is that the comparable studies should be homogeneous.

The objective of meta-analyses in some studies is to check whether their findings differ due to targeted populations, non-similarity in data collection, inclusion or exclusion criteria, which may lead to heterogeneity among the studies. A modification of the Cochran Q score, called the Higgins score $I^2 = \frac{(Q-df)}{df}$, was devised as a statistical method to assess the level of heterogeneity among studies. However, A hidden problem exists in both methods (Shanmugam et al., 2024; Van den Noortgate & Onghena, 2024; Chowdhury et al., 2024; Deeks et al., 2023).

The heterogeneity statistic I^2 is biased in small meta-analyses (Van den Noortgate & Onghena, 2024; Chowdhury et al., 2024; Deeks et al., 2023; Greenwood et al., 2022; Sahdra et al., 2024; Ni et al., 2024; Boult, 2024). This flaw is not trivial to detect. Specifically, when Cochran's Q score is less than the degrees of freedom (df) in meta-analytics, the Higgins score attains a negative value, which violates the assumption of a chi-squared distribution for the Higgins score. Specifically, I^2 values were interpreted as follows: (a) I^2= 0% denoted an absence of heterogeneity, (b) I^2 = 25% indicated low heterogeneity, (c) I^2 = 50% suggested moderate heterogeneity, (d) I^2 > 75% pointed to high heterogeneity, and (e) I^2 = 100% represented maximum heterogeneity, as an example. There is a level of subjectivity in the interpretation of the Higgins score. For that, we quote from another published article (Sahdra et al., 2024): "In the Cochrane Handbook, values up to 40% are interpreted as insignificant, 30−60% as moderate, 50−90% as substantial, and 75−100% as considerable heterogeneity" Deeks et al. (2023).

We are not disputing meta-analytic work but rather questioning the preamble of assessing the level of heterogeneity. Unless the studies compared in meta-analytics are homogeneous, they are not suitable for checking consistency in their findings. Therefore, the Higgins score needed to be repaired, and it was done in a recently published article (Shanmugam et al., 2024). This represents a critical and pivotal turning point in the practice of meta-analysis. This article further points out the usefulness of recently published method (Shanmugam et al., 2024) in revising published and questionable interpretations.

Meta-analysis is often practiced using the Higgins statistic. There are demonstrations in the meta-analytic literature (Shanmugam et al., 2024; Bloomfield & Rushby, 2024; Higgins et al., 2003; Khan, 2020; Brauer et al., 2024; Azmiardi et al., 2021; Alibrandi et al., 2023; Cai et al., 2024; Huang et al., 2021; Witarto et al., 2023; Isonne et al., 2024; Varghese et al., 2011; Paradisi et al., 2024; Hedges & Olkin, 2014; Ozguc et al., 2024; Ghafari et al., 2022; Robinson et al., 2023).

Reviewing the inferences made based on the Higgins score in 14 peer-reviewed published studies representing 133 databases may not be appropriate. This article serves as both a tutorial and an illustration of the recently published statistic, called the S^2 score for practitioners (Shanmugam et al., 2024). The statistic (S^2 score) is a rectified version of the Higgins score. We meticulously reviewed the literature, including prominent journals, to collect and examine applications and interpretations of the Higgins I^2 score in 14 published articles representing 133 datasets. We observed, based on the S^2 score, that 92 (69%) out of the 133 datasets of 14 published articles reversed to imply the homogeneity among the studies. This necessitates an importance to adapt the S^2 score (Shanmugam et al., 2024) for proper interpretations in future meta-analyses. The findings of this article aim to educate future practitioners in meta-analysis to draw correct conclusions based on Shanmugam et al.'s (2024) S^2 statistic, which refines the Higgins statistic. Accurate findings in meta-analysis can pave the way for informed health policy decisions. Some details of the evolution of the S^2 score are given in the following passage.

The data-based Cochran Q statistic follows a chi-squared probability structure with degrees of freedom (df) equal to $(\theta - 1)$, where θ denotes the number of studies in the meta-analysis. Higgins constructed and utilized the statistic $0 \leq I^2 = \left(\frac{Q-df}{df}\right) \leq 1.0$ to capture and interpret the level of heterogeneity in a study. The closer the Higgins score (I^2) is to zero, the lower the heterogeneity (and higher the homogeneity), although the relationship is not straightforward.

In this article, we probed, selected, and considered 133 published datasets from the literature that were meta-analyzed using the Higgins I^2 and interpreted (Table 1) only if their p-value was not significant (that is, p-value less than 0.001). For comparison purposes (Figure 1), the same 133 significant datasets were reevaluated using the computed value of a recent published S^2 statistic (Shanmugam et al., 2024).

Table 1. One hundred published articles were reappraised: Comparative performance on heterogeneity by the Higgins I^2 score versus S^2 score.

Published Articles	θ = # of Studies	I^2 Score	S^2 Score	Probability $Pr(S^2 < \chi^2_{1df})$	C: Confirmation R: Rejection	Support $(Q\|\theta)$
Ozguc et al. (2024) death anxiety with COVID	5	99.7 *	0.08	0.78	R	0.80
	2	99.5 *	0.89	0.34	R	0.50
	2	99.3 *	0.89	0.34	R	0.50
Ghafari et al. (2022) on mental health	19	99.3 *	0.36	0.55	R	0.95
	18	99.5 *	0.35	0.55	R	0.94
	20	99.9 *	0.36	0.55	R	0.95
	2	90.1 *	0.89	0.35	R	0.50
	2	94.5 *	0.89	0.35	R	0.50
	5	99.9 *	0.08	0.78	R	0.80
Azmiardi et al. (2021) on diabetes versus glycemic control	12	88 *	0.29	0.59	R	0.92
	8	84 *	0.21	0.65	R	0.88
	4	94 *	0.02	0.88	R	0.75
	6	89 *	0.13	0.72	R	0.83
	6	90 *	0.13	0.72	R	0.83
	9	91 *	0.24	0.63	R	0.89
	3	11	0.00	0.95	C	0.67
	6	70 *	0.13	0.71	R	0.83
	6	92 *	0.13	0.72	R	0.83
	2	98 *	0.89	0.35	R	0.50
	3	95 *	0.02	0.90	R	0.67
	7	52	0.18	0.67	C	0.86

Table 1. *Cont.*

Published Articles	θ = # of Studies	I^2 Score	S^2 Score	Probability $Pr(S^2<\chi^2_{1df})$	C: Confirmation R: Rejection	Support $(Q\,\|\,\theta)$
Brauer et al. (2024) on dose response	28	51	0.40	0.53	C	0.96
	27	0	2.06	0.15	C	0.96
Cai et al. (2024) on sleep disturbance during COVID-19	5	99.3 *	0.08	0.78	R	0.80
	29	99.8 *	0.40	0.53	R	0.97
	4	98.9 *	0.02	0.89	R	0.75
	12	99.7 *	0.29	0.59	R	0.92
	3	99.2 *	0.02	0.90	R	0.67
	4	97.5 *	0.02	0.89	R	0.75
Huang et al. (2021) on gallstones versus biliary tract cancer	7	79.0 *	0.18	0.68	R	0.86
	19	90.5 *	0.36	0.55	R	0.95
	15	82.4 *	0.33	0.57	R	0.93
	11	95.1 *	0.28	0.60	R	0.91
	8	95.5 *	0.21	0.65	R	0.88
	7	38.6	0.18	0.67	C	0.86
	7	85.7 *	0.17	0.68	R	0.86
	4	87.3 *	0.02	0.88	R	0.75
	8	64.5 *	0.21	0.65	R	0.88
	16	93.9 *	0.34	0.56	R	0.94
	2	17.1	0.82	0.36	C	0.50
	14	75.6 *	0.32	0.57	R	0.93
	12	94.9 *	0.29	0.59	R	0.92
Witarto et al. (2023) on endoscopic erosive esophagitis from 1997 to 2022	17	77 *	0.35	0.56	R	0.94
	92	96 *	0.45	0.50	R	0.99
	10	71 *	0.26	0.61	R	0.90
	2	91 *	0.89	0.35	R	0.50
	7	7	0.26	0.61	C	0.86
	7	85 *	0.17	0.68	R	0.86
	3	3	0.00	0.95	C	0.67
	50	85 *	0.43	0.51	R	0.98
	25	69 *	0.39	0.53	R	0.96
	38	30	0.44	0.51	C	0.97
	36	48 *	0.42	0.52	R	0.97
	10	3	0.49	0.48	C	0.90
	22	70 *	0.38	0.54	R	0.95
	4	67	0.02	0.88	C	0.75
	3	69	0.02	0.90	C	0.67
	17	56 *	0.35	0.55	R	0.94
	57	95 *	0.44	0.51	R	0.98
	39	91 *	0.42	0.52	R	0.97
	7	77 *	0.18	0.68	R	0.86
	6	61	0.13	0.71	C	0.83
	8	84 *		0.65	R	0.88
	8	0	1.60	0.21	C	0.88
	11	0	1.78	0.18	C	0.91
	6	93 *	0.13	0.72	R	0.83
	3	53	0.01	0.90	R	0.67
	2	84 *	0.89	0.35	R	0.50

Table 1. *Cont.*

Published Articles	θ = # of Studies	I^2 Score	S^2 Score	Probability $Pr(S^2 < \chi^2_{1df})$	C: Confirmation R: Rejection	Support $(Q\|\theta)$
Isonne et al. (2024) on vaccine literacy	3	90 *	0.02	0.90	R	0.67
	3	54	0.01	0.90	C	0.67
	5	84	0.08	0.78	C	0.80
	3	90	0.02	0.90	C	0.67
	3	54	0.01	0.90	C	0.67
Varghese et al. (2011) and Paradisi et al. (2024) on declining mental health of nurses during COVID-19.	6	97.7 *	0.13	0.72	R	0.83
	7	91.8 *	0.17	0.68	R	0.86
	8	96.5 *	0.21	0.65	R	0.88
	2	77.7	0.89	0.35	C	0.50
	4	92.2	0.02	0.88	C	0.75
	4	99.1 *	0.02	0.89	R	0.75
	4	98.8 *	0.02	0.89	R	0.75
	4	97.6 *	0.02	0.89	R	0.75
	2	68.6	0.89	0.35	C	0.50
	2	68.6	0.89	0.35	R	0.50
	2	90.9 *	0.89	0.35	R	0.50
	2	76.9	0.89	0.35	C	0.50
	7	97.5 *	0.17	0.68	R	0.86
	7	93.2	0.17	0.68	C	0.86
	7	93.9	0.17	0.68	C	0.86
	4	94.5	0.02	0.89	C	0.75
	4	99.5 *	0.02	0.89	R	0.75
	4	99.4 *	0.02	0.89	R	0.75
	4	98.5 *	0.02	0.89	R	0.75
	3	96.4 *	0.02	0.90	R	0.67
	2	98.5 *	0.89	0.34	R	0.50
	7	96.5 *	0.17	0.68	R	0.86
	3	80.1	0.02	0.90	C	0.67
	5	83.8	0.08	0.78	C	0.80
	10	99.5 *	0.26	0.61	R	0.90
	4	99.3 *	0.02	0.89	R	0.75
	9	99.6 *	0.23	0.63	R	0.89
	2	93.6 *	0.89	0.35	R	0.50
	2	98.5 *	0.89	0.34	R	0.50
	3	99.1 *	0.02	0.90	R	0.67
	2	54.9	0.88	0.35	C	0.50
	2	99.0 *	0.89	0.34	R	0.50
Chen et al. (2024) on Sleep spindles	19	39.7	0.37	0.54	C	0.95
Dutheil et al. (2023) on Myopia	12	98.9 *	0.29	0.59	R	0.92
	17	99.9 *	0.34	0.56	R	0.94
	40	99.9 *	0.42	0.52	R	0.98
	12	97.3 *	0.29	0.59	R	0.92
	4	100 *	0.02	0.89	R	0.75
	2	99.9 *	0.89	0.34	R	0.50

Table 1. *Cont.*

Published Articles	θ = # of Studies	I^2 Score	S^2 Score	Probability $Pr(S^2 < \chi^2_{1df})$	C: Confirmation R: Rejection	Support $(Q \mid \theta)$
Kerzhner et al. (2024) on pain symptoms	3	91.4 *	0.02	0.90	R	0.67
	3	90.3	0.02	0.90	R	0.67
	11	94.5 *	0.28	0.60	R	0.91
	5	92.4	0.08	0.78	C	0.80
	14	97.5 *	0.32	0.57	R	0.93
	7	92.3 *	0.17	0.68	R	0.86
	8	90.9 *	0.21	0.65	R	0.88
	13	92.5 *	0.31	0.58	R	0.92
	3	75.9	0.02	0.90	C	0.67
	3	46.0	0.01	0.91	C	0.67
Pahari et al. (2023) on tobacco usage in India	5	96.0 *	0.08	0.78	R	0.80
	8	99.8 *	0.21	0.65	R	0.88
Soheili et al. (2023) on efficacy and effectiveness of COVID-19 vaccines	5	77.1	0.08	0.78	C	0.80
	3	89.9	0.02	0.90	C	0.67
	11	79.9	0.28	0.60	C	0.91
	5	88.3	0.08	0.78	C	0.80
	9	75.1	0.24	0.63	C	0.89
	5	89.0	0.08	0.78	C	0.80
	9	73.4	0.24	0.63	R	0.89
	4	89.0	0.02	0.88	R	0.75
	4	44.3	0.02	0.88	R	0.75

* R and C refer to "confirmed" and "rejected", respectively, regarding the conclusions reached using the Higgins I^2 score in the meta-analysis.

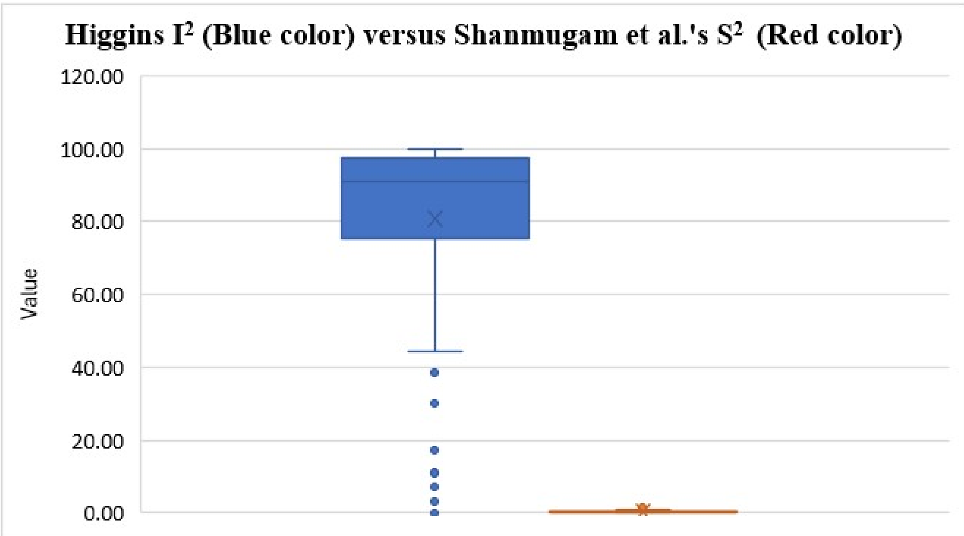

Figure 1. Comparison of the Higgins I^2 score and the S^2 score in terms of Box plots.

When the conclusion about the heterogeneity of studies, based on the Higgins score, is confirmed by the S^2 statistic in expression (1), it is recognized and coded as C (Table 1). Conversely, if the conclusion about heterogeneity derived from the Higgins I^2 is nullified by the S^2 statistic (score), it is recognized and coded as R (Table 1).

In summary, about 69% of the 133 published datasets received the code R. The codes C and R refer to corresponding to or rejecting of the statistic (1), respectively. Consequently, the code R warrants further scrutiny of the support for the Cochran Q score based on the number of studies (θ).

For this purpose, we could consider a regression-based concept on the correlation between Q and θ, or another competing probability-based option. This competing probability-oriented option could be the support for the outcome A by a related outcome B, as expressed in terms of the conditional probability $Pr(A|B)$ and the marginal probability, $Pr(A)$ in a logarithmic scale as follows:

$$Support\_function(A|B) = ln\left\{\frac{Pr(A|B)}{Pr(A)}\right\}$$

This function would capture and interpret an intricate causal level of B on A, as outlined in the recently published paper (Shanmugam et al., 2024). Notice that $Pr(A|B) > Pr(A)$. In this context, we consider $A = Q$ and $B = \theta$. Note that $\theta \geq 1$. When $\theta = 1$, the df is zero meaning there is no finite information. In other words, in meta-analytic studies, θ must be at least two (Deeks et al., 2023; Greenwood et al., 2022) for more detail on the logic of involving conditional and marginal probabilities to authenticate the influence of one event on another in a stochastic environment. We would derive a support measure for using the statistic (1) instead of using the Higgins statistic I^2. In the end, we compute the support measure for the 133 published datasets and interpret it in the context of meta-analysis. We discuss and conclude that, in many of the studies, the S^2 statistic is better than the statistic I^2.

2. A Refined Meta-Analytics Methodology

Researchers have faithfully utilized Higgins statistic to compare the implications of comparable studies on a given topic. To the best of our knowledge, no prior research has investigated the appropriateness and suitability of the Higgins score. We alert researchers with the results of a recently published article (Shanmugam et al., 2024). Our alert concerns the non-independence between the Cochran score Q and the df. We suggest that researchers use the method correctly as recently outlined (Shanmugam et al., 2024). The new score is named as the S^2 score:

$$S^2 = \left(\frac{I^2 - E(I^2)}{\sqrt{Var(I^2)}}\right] = \chi^2_{1df} = \left(\frac{\frac{(\theta+11)}{6(\theta-1)} - \left(1 + \frac{df}{Q}\right)}{\sqrt{3\left|1 - \frac{(\theta+1)}{2(\theta-1)}\right|}}\right)^2 \quad (1)$$

where θ and χ^2_{1df} denote, respectively, the number of studies with a discrete uniform distribution and a chi-squared random variable with one df. For simplicity in computation, we recognize $\frac{df}{Q}$ as $(I^2 + 1)$. In this article, we revisit the data that appeared in published articles and reappraise their conclusions using the new S^2 statistic. When our appraisal using S^2 score codes the results as C, meaning correspond, or R, meaning reject, the conclusions are based on using Higgins score I^2. To observe the frequency of the codes (C) or (R), refer to Table 1. The number of rejections is computed and commented on as an alert for researchers conducting meta-analytic studies. Because of the transformation earlier, the df also undergoes a transformation.

As we recall from Shanmugam et al. (2024), where θ denotes the number of studies in the meta-analytic work, a transformation $w = -2ln\left(\frac{1+df}{\theta}\right)$, and $Q > 0$ denote, respectively, the logarithmic transformation of the number of studies, and the df, as employed

(Greenwood et al., 2022). The marginal probability density function (PDF) of the function of the df in (2) was specified in Shanmugam et al. (2024) as follows:

$$f(w) = (1 - \frac{1}{\theta})^{-1}(\frac{1}{2})e^{-(\frac{w}{2})};\ 0 < w < 2ln\theta \quad (2)$$

The conditional PDF of the Cochran score Q for a given w is a gamma probability density as shown in (3):

$$g(Q|w) = \frac{e^{-Q/2}Q^{\frac{(\theta e^{-(\frac{w}{2})}-1)}{2}-1}}{2^{\frac{(\theta e^{-(\frac{w}{2})}-1)}{2}}\Gamma(\frac{(\theta e^{-(\frac{w}{2})}-1)}{2})};\ Q > 0 \quad (3)$$

The authors in Shanmugam et al. (2024) showed that the covariance, $Corr(Q, df) = 0$, where $df = (\theta e^{-(\frac{w}{2})} - 1)$. A caution is necessary to point out here that zero correlation does not imply independence between the Cochran score Q and the degrees of freedom df. This is true because only in the case of bivariate normality of the underlying data pattern does zero correlation between two statistics imply their stochastic independence. In other words, the zero correlation between the Cochran score $Q > 0$ and the degrees of freedom $df \geq 1$ is not a support measure to suggest that the Shanmugam et al.'s statistic S^2 is better than the incorrect Higgins statistic I^2 which has a flaw. Hence, we seek support based on the probability risk, as pointed out in an earlier paragraph above.

Equating the Cochran score Q and df with the events A and B, respectively, in the above formula, we obtain a support measure in (4), after the Taylorized approximation of $g(Q|w)$ and the integration:

$$h(Q) = \int_0^{2ln\theta} g(Q|w)f(w)dw$$

That is

$$Support(Q|\theta) = ln\{\frac{g(Q|w)}{h(Q)}\} \approx \left(1 - \frac{1}{\theta}\right); \theta \geq 2 \quad (4)$$

Realize that when the number of studies θ increases, the support level for the Cochran score Q attains its maximum at 1.0. The distribution of the number of studies is discrete uniform.

3. Discussions

The studies that are compared (Boult, 2024) are described a significant sense of dying anxiety due to pandemics among the general population. Specifically considered in group (1) are the age group 18–54 years, and group (9) females (Sahdra et al., 2024). Significant meta-analytic results are published (Ni et al., 2024) on the global prevalence of met versus unmet needs for mental health care among adolescents, with sample sizes of (1) fewer than 50, (2) 501–1000, and (3) greater than 1001 in the met group, as well as adolescents with sample sizes of (4) fewer than 500, (5) 501–1000, and (6) greater than 1001 in the unmet group. A meta-analytic summary of studies investigating the connection between diabetes and glycemic control to maintain healthy behavior concluded statistically significant effects on reducing HbA1c across all groups (1) through (12), as reported (Boult, 2024).

A meta-analytic result on the dose-response significant relationship using a linear model, with and without interaction, is reported (Boult, 2024). Meta-analytic study results are summarized (Boult, 2024), as they describe the significant impact of COVID-19 on sleep disturbances across all continents: America, Asia, Asia & Europe, Europe, Oceania, and South America. The significant studies on gallstones versus biliary tract cancer, except in groups around 2000 and in groups with no record, are detailed (Bloomfield & Rushby, 2024).

Meta-analytic significant results are published (Khan, 2020, p.197) on endoscopic erosive esophagitis from 1997 to 2022, stratified by gender, individuals above 60 years old, all races, employment status, education level, BMI above 25 kg/m^2, obesity, hypertension, hypertriglyceridemia, hernia, H. pylori infection, gastric ulcer, atrophic gastritis, PPI use, and antacid use. However, no significant results were found for marital status, those with more than 12 years of education, hyperglycemia, dyslipidemia, hypercholesterolemia, high LDL-C, duodenal ulcer, NAFLD, NSAID use, or H2RA use.

Significant results on vaccine literacy only among individuals interacting with VL are reported (Brauer et al., 2024). Studies on the declining mental health of nurses during COVID-19, using meta-analytic concepts and the Higgins score, are summarized (Higgins et al., 2003; Azmiardi et al., 2021). These studies reveal significant heterogeneity among nurses with mild, moderate, or severe anxiety, single or married status, severe stress, mild depression, PTSD, insomnia, and anxious individuals of European or eastern origin but not from Mediterranean origin. While studies have shown that spindles during non-rapid eye movement sleep prioritize memory with tags (Alibrandi et al., 2023) reports no significant effect on tags.

Myopia is recognized as a severe global health issue affecting quality of life. meta-analytic results on Myopia reveal significant heterogeneity among categories before 2005, 2005–2015, and after 2015 in Asia, Europe, and North America, as summarized (Cai et al., 2024). Meta-analytic results on body pain due to pandemics in several studies are detailed (Huang et al., 2021), highlighting significant heterogeneity among hospitalized patients of both genders experiencing chest pain.

Meta-analytic results on excessive tobacco use during 2010–2015 versus 2016–2022, concluding significant heterogeneity, are summarized (Witarto et al., 2023). The efficacy and effectiveness of COVID-19 vaccines in estimating immunogenicity, benefits, or side effects using meta-analytic principles revealed no significant heterogeneity among them, as evaluated (Isonne et al., 2024; Varghese et al., 2011; Paradisi et al., 2024; Hedges & Olkin, 2014; Ozguc et al., 2024; Ghafari et al., 2022; Hartmann et al., 2024). The recent methodology based on the S^2 score (Shanmugam et al., 2024) upholds (C) some findings while reversing (R) other findings, highlighting significant heterogeneity as displayed in Table 1.

Mental health problems significantly affect the quality of life, impacting decision -making (Shanmugam, 2023) and causing non-harmonious interpersonal communication under stress. Rectifying and applying meta-analysis is essential for addressing mental health issues. The subjectivity in judging heterogeneity in published articles on mental health could be replaced by an objective method using the S^2 score, as demonstrated in this article. A reason for this subjectivity in the Higgins score is that the score neglected the domain of the observable space in the chi-squared distribution. The S^2 score correctly rectified this error and hence corrected their bias using chi-squared distributional properties. In another article, the authors are developing a methodology on how the heterogeneity decreases due to an additional study on a topic of interest using the rectified meta-analysis with elasticity and with application to addressing mental health issues.

4. Limitations

In our literature review, we did not find any ongoing research addressing the merits or shortcomings of the Higgins score. However, our improvement to the Higgins score is expressed in Equation (1). It should be noted that the parameter θ represents the number of studies on a chosen topic in meta-analytics. Without loss of generality, the number of studies in any meta-analytic topic is never considered final. When an additional study is included in the literature on the meta-analytic topic, the parameter θ increases by one. The significance or even the non-significance of the expression (1) should be assessed with an increased value for the parameter θ. This is a restricted limitation. In this sense, we searched the literature to collect and scrutinize meta-analytic studies that utilized the Higgins score. By any means, we do not claim that our literature search is complete. We have limited our meta-analysis to 133 datasets from 14 articles to demonstrate that the S^2 score, as proposed (Shanmugam et al., 2024), confirms some but not all conclusions are based on the Higgins score. We did not apply the inclusion or exclusion principles in the collection and scrutiny of the articles from the literature Both authors conducted the search, scrutinized the articles, and verified all conclusions using the Higgins I^2 score as well as the S^2 score. There was no cognitive bias, as both authors reached consensus on the findings. We suggest future research directions to evaluate the merits and shortcomings of the S^2 score in comparison with the Cochrane Q score and the Higgins score.

5. Conclusions

Some observations based on the correlation matrix in Table 2 are noteworthy. The support, Support(Q|θ) for the Cochran score understandably increases as the number of studies increases. Also, when the Higgins score I^2 increases, the Shanmugam et al.'s score S^2 decreases. There is no independence between the Cochran Q score and the degrees of freedom $df = \theta - 1$. Interestingly, as the support for the Cochran score Q by the number of studies θ increases, the score S^2 decreases leading to the conclusion that the studies are homogeneous because of the lower S^2. In conclusion, the results indicate that the Shanmugam et al.'s (2024) statistic S^2 is more robust and hence, preferrable to the Higgins statistic I^2 to detect whether the studies are significantly heterogeneous. In this paper the authors have illustrated the usefulness of practicing meta-analytics with rectification using examples on data on cognitive impairment, depression, and COVID-19 vaccination. The authors are working on addressing mental health problems using their meta-analysis rectified approach with an elasticity concept in a separate article.

Table 2. Correlation among the variables.

	No Studies	Higgins I^2	S^2	Support
No studies	1			
Higgins	−0.04097	1		
S^2	0.130017	−0.31767	1	
Support	0.595315	−0.05943	−0.2445	1

Author Contributions: Conceptualization—R.S. and K.P.S.; Methodology—R.S. and K.P.S.; Validation—R.S. and K.P.S.; Formal analysis—R.S.; Investigation—R.S. and K.P.S.; Writing—R.S. and K.P.S.; Writing—Review & Editing—R.S. and K.P.S.; Supervision—K.P.S.; Funding acquisition—K.P.S. All authors have read and agreed to the published version of the manuscript.

Funding: The project was partially supported through the funding received from the Affordable cures Funding of HCSC/BCBST, Grant Number 1122327.

Data Availability Statement: The data sets used in this article are available in the public domain.

Acknowledgments: The authors are grateful to their home institutions for supporting the research done on the project.

Conflicts of Interest: The authors declare no conflicts of interest. Role of the Funder/Sponsor: The funder or sponsor had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

References

Alibrandi, A., Gitto, L., Limosani, M., & Mustica, P. F. (2023). Patient satisfaction and quality of hospital care. *Evaluation and Program Planning*, *97*, 102251. [CrossRef] [PubMed]

Azmiardi, A., Murti, B., Febrinasari, R. P., & Tamtomo, D. G. (2021). The effect of peer support in diabetes self-management education on glycemic control in patients with type 2 diabetes: A systematic review and meta-analysis. *Epidemiology and Health*, *43*, e2021090. [CrossRef] [PubMed]

Bloomfield, R., & Rushby, J. (2024). Confidence in Assurance 2.0 cases. In *The practice of formal methods: Essays in honour of cliff jones, part 1* (pp. 1–23). Springer Nature.

Boult, C. (2024). Degrees of epistemic criticizability. *The Philosophical Quarterly*, *74*, 431–452. [CrossRef]

Brauer, R., Ormiston, J., & Beausaert, S. (2024). Creativity-fostering teacher behaviors in higher education: A transdisciplinary systematic literature review. *Review of Educational Research*, 1–30. [CrossRef]

Cai, H., Chen, P., Jin, Y., Zhang, Q., Cheung, T., Ng, C. H., & Feng, Y. (2024). Prevalence of sleep disturbances in children and adolescents during COVID-19 pandemic: A meta-analysis and systematic review of epidemiological surveys. *Translational Psychiatry*, *14*, 12. [CrossRef]

Chen, P., Hao, C., & Ma, N. (2024). Sleep spindles consolidate declarative memory with tags: A meta-analysis of adult data. *Journal of Pacific Rim Psychology*, *18*, 18344909241226761. [CrossRef]

Chowdhury, M. I. H., Rakib, M. H., Das, C., & Hossain, M. Z. (2024). Tree species germination: A comprehensive meta-analysis and its implications for pre-sowing treatment in bangladesh. *Journal of Soil, Plant and Environment*, *3*, 24–40. [CrossRef]

Deeks, J. J., Bossuyt, P. M., Leeflang, M. M., & Takwoingi, Y. (Eds.). (2023). *Cochrane handbook for systematic reviews of diagnostic test accuracy* (pp. 204–244). John Wiley & Sons.

Dutheil, F., Oueslati, T., Delamarre, L., Castanon, J., Maurin, C., Chiambaretta, F., & Navel, V. (2023). Myopia and near work: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health*, *20*, 875. [CrossRef]

Ghafari, M., Nadi, T., Bahadivand-Chegini, S., & Doosti-Irani, A. (2022). Global prevalence of unmet need for mental health care among adolescents: A systematic review and meta-analysis. *Archives of Psychiatric Nursing*, *36*, 1–6. [CrossRef]

Greenwood, H., Krzyzaniak, N., Peiris, R., Clark, J., Scott, A. M., Cardona, M., & Glasziou, P. (2022). Telehealth versus face-to-face psychotherapy for less common mental health conditions: Systematic review and meta-analysis of randomized controlled trials. *JMIR Mental Health*, *9*, e31780. [CrossRef]

Hartmann, N. N., Wieland, H., Gustafson, B., & Habel, J. (2024). Research on sales and ethics: Mapping the past and charting the future. *Journal of the Academy of Marketing Science*, *52*, 653–671. [CrossRef]

Hedges, L. V., & Olkin, I. (2014). *Statistical methods for meta-analysis* (pp. 1–250). Academic Press.

Higgins, J. P., Thompson, S. G., Deeks, J. J., & Altman, D. G. (2003). Measuring inconsistency in meta-analyses. *BMJ*, *327*, 557–560. [CrossRef] [PubMed]

Huang, D., Joo, H., Song, N., Cho, S., Kim, W., & Shin, A. (2021). Association between gallstones and the risk of biliary tract cancer: A systematic review and meta-analysis. *Epidemiology and Health*, *43*, e2021011. [CrossRef]

Isonne, C., Iera, J., Sciurti, A., Renzi, E., De Blasiis, M. R., Marzuillo, C., & Baccolini, V. (2024). How well does vaccine literacy predict intention to vaccinate and vaccination status? A systematic review and meta-analysis. *Human Vaccines & Immunotherapeutics*, *20*, 2300848.

Kerzhner, O., Berla, E., Har-Even, M., Ratmansky, M., & Goor-Aryeh, I. (2024). Consistency of inconsistency in long-COVID-19 pain symptoms persistency: A systematic review and meta-analysis. *Pain Practice*, *24*, 120–159. [CrossRef]

Khan, S. (2020). *Meta-analysis* (pp. 195–216). Springer Nature. Singapore.

Ni, Y. X., Liu, X. H., He, L., Wen, Y., & You, G. Y. (2024). Mobile application-based interventions for people with heart failure: A systematic review and meta-analysis. *Journal of Nursing Management*, *1*, 6859795. [CrossRef]

Ozguc, S., Kaplan Serin, E., & Tanriverdi, D. (2024). Death anxiety associated with coronavirus (COVID-19) disease: A systematic review and meta-analysis. *OMEGA-Journal of Death and Dying*, *88*, 823–856. [CrossRef]

Pahari, S., Barman, D., & Talukdar, R. (2023). Tobacco usage in India: A meta-analysis of evidence drawn from regional studies between 2010 and 2022. *Tropical Medicine & International Health*, *28*, 699–709.

Paradisi, M., Matera, C., & Nerini, A. (2024). Feeling important, feeling well. The association between mattering and well-being: A meta-analysis study. *Journal of Happiness Studies*, *25*, 4. [CrossRef]

Robinson, T., Ali, M. U., Easterbrook, B., Hall, W., Jutras-Aswad, D., & Fischer, B. (2023). Risk-thresholds for the association between frequency of cannabis use and the development of psychosis: A systematic review and meta-analysis. *Psychological Medicine*, *53*, 3858–3868. [CrossRef]

Sahdra, B. K., Ciarrochi, J., Klimczak, K. S., Krafft, J., Hayes, S. C., & Levin, M. (2024). Testing the applicability of idionomic statistics in longitudinal studies: The example of ‘doing what matters’. *Journal of Contextual Behavioral Science*, *32*, 100728. [CrossRef]

Shanmugam, R. (2023). *Data-guided healthcare decision making* (pp. 114–119). Cambridge University Press.

Shanmugam, R., Tabatabai, M., Wilus, D., & Singh, K. P. (2024). The bounds of meta-analytics and an alternative method. *Epidemiology and Health*, *46*, e2024016. [CrossRef] [PubMed]

Soheili, M., Khateri, S., Moradpour, F., Mohammadzedeh, P., Zareie, M., Mortazavi, S. M. M., & Moradi, Y. (2023). The efficacy and effectiveness of COVID-19 vaccines around the world: A mini-review and meta-analysis. *Annals of Clinical Microbiology and Antimicrobials*, *22*, 42. [CrossRef] [PubMed]

Van den Noortgate, W., & Onghena, P. (2024). Harnessing available evidence in single-case experimental studies: The use of multilevel meta-analysis. *Psychologica Belgica*, *64*(1), 166–184. [CrossRef]

Varghese, A., George, G., Kondaguli, S. V., Naser, A. Y., Khakha, D. C., & Chatterji, R. (2011). Decline in the mental health of nurses across the globe during COVID-19: A systematic review and meta-analysis. *Journal of Global Health*, *11*, 1–15. [CrossRef]

Witarto, A. P., Witarto, B. S., Pramudito, S. L., Ratri, L. C., Wairooy, N. A. P., Konstantin, T., & Gusnanto, A. (2023). Risk factors and 26-years worldwide prevalence of endoscopic erosive esophagitis from 1997 to 2022: A meta-analysis. *Scientific Reports*, *13*, 15249. [CrossRef]