COMMENTARY

Ten circumstances and solutions for finding the sample mean and standard deviation for meta-analysis

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Abstract

A common problem in meta-analyses is the unavailability of mean and standard deviation (SD). Unfortunately, only having values of the median, interquartile range (IQR), or range cannot be directly utilized for meta-analysis. Although some estimation and conversion methods have been proposed in the past two decades, there were no published and user-friendly tools developed based on multiple scenarios of missing SD. Therefore, this study aimed to provide a collection of possible circumstances of missing sample means or SD with solutions for teaching and research. A total of 10 common circumstances of missing SD or mean could have available statistics of *p* value, *t* value, *z* score, confidence interval, standard error, median, IQR, and range. Teachers and investigators can use relevant formulas for finding the sample mean and SD according to the available circumstance. Due to the complicated computations, our team provides a free available spreadsheet. With ever-evolving statistical methods, some formulas may be further improved in the future; therefore, it is recommended to involve statisticians in evidence-based practice or systematic reviews.

Keywords Data conversion, Data estimation, *p* value, *t* value, *z* score, Interquartile, Range

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Background

Meta-analysis is a quantitative analytic method only to be applied within an appropriate context in a systematic review and is an important method for having an overview of the evidence body of a specific topic, but "meta-analysis metastasis" have raised concerns in the academic field [1, 2]. Problematic data processing or analysis hides in many syntheses that threaten the quality of the evidence [3]. A recent study demonstrated the underlying causes of the retraction of meta-analysis shifted from academic ethical violations to methodological flaws including inappropriate data conversion or estimation [4]. The retractions of meta-analysis manuscripts for violating the academic ethics such as conflicts of author sequences, plagiarism, or other issues by the Committee on Publication Ethics (COPE) have been decreased from 80% to 40% before 2020. On the other hand, methodological flaw becomes a critical

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reason for the retraction of meta-analysis manuscript with an increasing trend from < 10 to 40%. In this aspect, knowledge and ability of data conversion and estimation should be the core skills for meta-analysis researchers. The objective of this study was to raise discussion on the circumstances and current solutions without adequate data for meta-analysis. Accordingly, this article includes a collection of possible circumstances of missing sample means or standard deviation (SD) with solutions for teaching and research.

Methods

At Cochrane Taiwan and Wan Fang Hospital, two senior researchers (C-F.C. and E.K.) reviewed the designated textbooks and systematic reviews and screened reference lists for other potential references. Additional systematic reviews were identified by the systematic search, and handbooks were broadly used in evidence-based medicine (Supplementary 1 and 2). Based on the identified references, they listed possible circumstances of no adequate data for meta-analysis and sought formulas for identifying sample mean or SD in each circumstance. Following double-checking the circumstances and solutions, the working group categorized the identified circumstances and solutions and built an Excel tool for estimation and conversion of each circumstance in which solutions are based on the Cochrane Handbook and the study by Wan et al. (Supplementary 3) [5–7].

Results

The working group listed 10 principal circumstances and categorized them into two general categories, including (a) descriptive statistics of a single group (within-group circumstances) and (b) effect estimates

of two treatment groups (between-group circumstances; Fig. 1).

Within-group circumstances
Circumstance-1: only within-group standard error is available
Within-group SD can be obtained by multiplying within-group standard error (SE) by the square root of the sample size (formula-1; all formulas are placed in Supplementary 4) [6].

Circumstance-2: only within-group confidence interval is available
The confidence interval (CI) for a mean of a group can be converted to the corresponding SE and SD. If an original study has indicated what statistical test was used, investigators have to estimate SE and SD using formula-2 to formula-5 based on the corresponding distribution. According to the Cochrane Handbook, if a primary report does not describe which statistical test has been used, the sample size of each group ($\geqq100$ or < 100) might be a clue of the formula selection in terms of the decision between z distribution (formula 2 and formula 3) and t distribution (formula 4 and formula 5) [6].

Circumstance-3: descriptive statistics are available but no mean and SD
Investigators might estimate within-group mean and SD according to formulas in the Cochrane Handbook and an article by Hozo et al. [6, 8] when encountering the circumstance of no mean or SD but other descriptive statistics, including median, minimum, maximum, the first quartile, and the third quartile are available. For instance, SD could be simply estimated by dividing the interquartile range (IQR) by 1.35 [6], or selecting a formula according to the range of the sample size (formulas 6 and 7) [8]. However, the divisor of 1.35 only applies when the
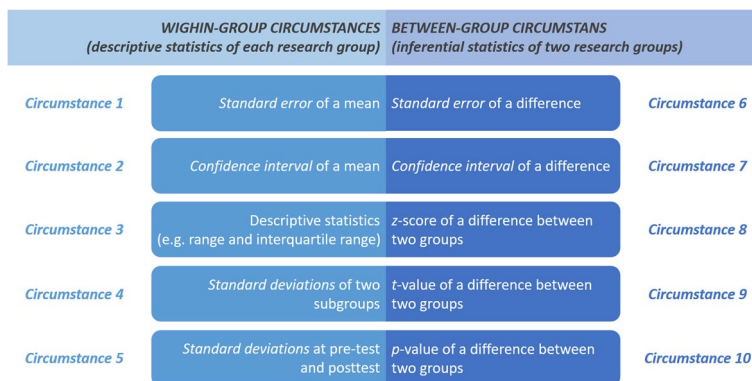

	WITHIN-GROUP CIRCUMSTANCES (descriptive statistics of each research group)	BETWEEN-GROUP CIRCUMSTANS (inferential statistics of two research groups)	
Circumstance 1	*Standard error* of a mean	*Standard error* of a difference	*Circumstance 6*
Circumstance 2	*Confidence interval* of a mean	*Confidence interval* of a difference	*Circumstance 7*
Circumstance 3	*Descriptive statistics* (e.g. range and interquartile range)	*z*-score of a difference between two groups	*Circumstance 8*
Circumstance 4	*Standard deviations* of two subgroups	*t*-value of a difference between two groups	*Circumstance 9*
Circumstance 5	*Standard deviations* at pre-test and posttest	*p*-value of a difference between two groups	*Circumstance 10*

Fig. 1 Ten convertible or estimable circumstances of the missing sample mean or standard deviation

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sample size is large and investigators may overestimate the SD when the sample size is small, which hinders general use. Although the sample size is taken into account in the selection of the conversion formula proposed by Hozo et al. [8], the formulas themselves are sample size-independent. Therefore, it would be more appropriate to use sample size-dependent formulas, which were modified and developed by Wan et al. [9] and Lou et al. [10] on the basis of Hozo's [8] method. Because primary study may present descriptive statistics in different ways, investigators could find sub-circumstance with corresponding estimating formulas as follows:

Sub-circumstance 3.1: only minimum, median, and maximum are available   Lou et al. and Wan et al. proposed sample size-dependent methods for the estimation of mean and SD. Lou et al. introduced an optimal weight (*w*) into the approximation of a mean with a function of sample size (*n*) (formula 8) [7, 10]. Then, the mean could be estimated using the function of n with minimum, median, and maximum (formula 9). SD could be estimated by the function of *n* and range with the inverse function of the percentile of the standard normal distribution (formula 10).

Sub-circumstance 3.2: only median and quartiles are available   Similarly, modified methods result in more precise estimations for mean and SD from median and quartiles using formulas 11 and 12 [7, 8, 10, 11].

Sub-circumstance 3.3: minimum, Q1, median, Q3, and maximum are available   Estimations SD in this sub-circumstance, one can use the modification of Bland's methods proposed by Lou et al. based on the same rationale (formulas 13 and 14) [10, 11].

Sub-circumstance 3.4: only range is available but without minimum and maximum   The formulas regarding estimations of the mean and SD from minimum and maximum can work if the original report provides a range without minimum and maximum [7, 10]. In consequence, sub-circumstance 3.4. is based on the formula 10 in sub-circumstance 3.1. Nevertheless, formula 9 cannot estimate a mean from range without minimum and maximum, the median is regarded as the mean in sub-circumstance 3.4 if data do not violate the assumption of normality.

Sub-circumstance 3.5: only interquartile range is available but without Q1 and Q3   The formulas regarding estimations of the mean and SD from the first quartile, and the third quartile can work if the original report provides an interquartile range (IQR) without Q1 and Q3 [7, 10].

Hence, sub-circumstance 3.5 is based on formula 12 in sub-circumstance 3.2. However, formula 11 cannot estimate a mean from IQR without the Q1 and Q3, and the median is regarded as the mean in sub-circumstance 3.5 if data does not violate the assumption of normality.

Circumstance-4: pooled SD from two subgroups
On occasion, investigators are intended to combine two subgroups into a single group so SD in the two subgroups should be pooled together. Two well-established formulas, either proposed by Cohen or presented in the Cochrane Handbook [6, 12]. Under the assumption of homogenous variance, investigators can choose the "Cohen" method to combine the SDs (formula 15). If means are available for each subgroup, investigators can choose the formula introduced in the Cochrane Handbook because the equation takes the mean into account, and the pooled SD will be calculated (formula 16).

Circumstance 5: SD for the change score
When studies provide the mean and SD of baseline and post-intervention, investigators can easily calculate the mean of change by subtracting the mean of post-intervention from the mean of baseline. However, it would be difficult to obtain the SD of changing scores. Under the assumption of no variation of outcome measurements, reviewers can follow these steps to acquire SDs for the change score.

> Step-1: Seek for studies investigating the same intervention groups using identical outcome measurements.
> Step-2: Make sure the mean and SD of the baseline, post-intervention, and change score are available.
> Step-3: Calculate the correlation coefficient of the experimental group ($CORR_E$) and comparator group ($CORR_C$) using formulas 17 and 18.
> Step-4: Obtain the overall CORR by averaging the $CORR_E$ and $CORR_C$.
> Step-5: Impute SD for the change score using SD at both baseline and post with overall CORR using formula 19.

Between-group circumstances
Circumstance 6: available data is SE of difference between two groups
Within-group SD from SE of the difference between two groups is an approximate estimate using the average SD for each group (formula 20). The "within-group SD" refers to the average SD of two intervention groups. Thus, it is an estimated SD for each treatment group with

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the same value. This method does not seriously bias the result of meta-analysis since a pooled estimate is usually based on mean difference or relative effect and SE of the effect measurement, although formula 20 only produces an approximation of SD.

Circumstance 7: only effect estimates with corresponding CI are available

When a difference and its associated CI were reported in a study, SE can be calculated from CI. If investigators would like to convert CI into SE or SD, the calculation firstly has to be based on the statistical test in the primary study. Nevertheless, in the primary report without information on the statistical test, the sample size of each group ($\geqq 60$ or < 60) might be a clue of the formula selection in terms of the decision between z distribution (formula 2) and t distribution (formula 4) [6]. Then, SD for each treatment group could be estimated using formula 20.

Circumstance 8: only effect estimates with the z score between two groups are available

SE of the difference between the two groups could be estimated by dividing the effect estimate using z score (formula 21). Within-group SD in this circumstance can also be estimated using formula 20.

Circumstance 9: only effect estimates with the t value between two groups are available

SE of the difference between two groups can be calculated using formula 22. Then, the estimated SD for each treatment group could be obtained using formula 20.

Circumstance 10: only effect estimates with p value between two groups are available

Investigators have to know what the p value for (z distribution or t distribution) and to estimate within-group SD according to the following steps:

> Step-1: Calculate the z score or t value from p value [13].
> Step-2: Calculate SE of the mean difference between two groups by dividing the effect estimate using z score (formula 21) or t value (formula 22).
> Step-3: Calculate the average SD for each group based on the SE of mean difference between two groups (formula 21).

Discussion

Understanding the circumstance and the existing solutions is important to researchers of meta-analysis because appropriate conversion or estimations could increase precision and reduce the risk of bias due to incomplete reporting. On the contrary, imprecision and

biased estimates would be due to inappropriate exclusions of some irregular outcome reporting in a meta-analysis [14]. Due to the complicated computations, our team provides a free available spreadsheet calculator for teaching and research based on the formulas and scenarios in the present article. Based on statistics standpoints, we placed the between-group circumstance after the within-group circumstance and order the sequence of sub-circumstances in the Excel tool after the working group meeting. The tool could help investigators without statistical background to estimate or convert data more appropriately. Before using the tool, however, investigators ought to contact corresponding authors to obtain desired statistics. If the incomplete reporting is out of the circumstances in the present article, investigators might use multiple imputations based on a sufficient number of studies with complete information [14]. Then, investigators can only perform qualitative synthesis if they do not receive a response from the original authors and imputation cannot be succeeded due to insufficient studies. To keep the quality of meta-analysis, involving statisticians or experienced researchers in evidence-based practice or study is still recommended [6, 15].

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13643-023-02217-1.

Additional file 1: Supplementary file 1. Search for relevant systematic reviews. **Supplementary file 2.** List of reviewed textbook and systematic review. **Supplementary file 3.** Resource of the DECoMA file. **Supplementary file 4.** Formulae of data estimation and conversion.

Availability and requirements
Project name: Spreadsheet-Enhanced Tools for Evidence-Based Practice (SET-EBP)
Project home page: Nil.
Operating system: Microsoft Windows
Programming language: Visual Basic
Other requirements: Microsoft Excel 2010 or later
License: Open Source, free

Authors' contributions
Conceptualization: E.K. Data curation: E.K. Formal analysis: E.K. Investigation: K.Y.C., M.Y.L., C.F.C., and E.K. Methodology: C.F.C and E.K. Interpretation: K.Y.C., M.Y.L., C.F.C., and E.K. Supervision: C.F.C. Visualization: E.K. Writing—original draft: K.Y.C. and M.Y.L. Writing—review and editing: C.F.C. and E.K. The authors read and approved the final version of the manuscript.

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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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