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Reply to Takefuji "Methodological limitations of linear parametric analysis in biological research: A critical review of NEO-Five personality traits and sleep characteristics study"

In a commentary, Takefuji discussed the potential limitations of employing linear parametric methods in analyzing biomedical data and drew a link to our systematic review and meta-analysis which synthesized the existing evidence on the association between personality traits and sleep characteristics. In our meta-analytic review, the findings indicated that poor sleep quality was associated with different NEO-five personality dimensions, including lower levels of openness, conscientiousness, extraversion, and agreeableness and a higher level of neuroticism. In addition, shorter sleep duration was found to be associated with a higher degree of neuroticism. While we appreciate Takefuji's insight and acknowledge that linear parametric methods may oversimplify other non-linear relationships, we believe that their impact on our results regarding the association between personality traits and sleep characteristics is limited. In addition, we recognize the challenges inherent in implementing Takefuji's suggested statistical approaches in the context of meta-analyses and welcome further discussion on advancing methodologies in this field.

There has been research showing non-linear relationships between sleep, especially sleep duration, and certain medical and functional outcomes. For example, studies have demonstrated curvilinear associations between sleep duration and mortality, cardiovascular diseases, and academic performance, with both excessively long and short sleep duration linking to increased risks and poorer outcomes [1–3]. However, when it comes to personality traits as a psychological construct, there is limited empirical evidence supporting a non-linear relationship between sleep and personality traits. While most studies have indicated that shorter sleep duration is associated with a higher level of neuroticism, with one study reporting contradictory findings [4], there is a lack of research showing non-linear relationships between sleep quality and other outcomes, such as mental health, cognitive functioning, or performance, leaving this area underexplored. Although only one study has suggested nonlinear relationships between certain personality traits and performance – such as between conscientiousness and job performance, and between neuroticism and task performance [5] - other studies have found contradictory evidence of curvilinearity [6,7]. Upon a careful review of the existing literature on the relationship between personality traits and sleep characteristics, particularly among the studies included in our current meta-analysis, the evidence has primarily pointed towards a linear relationship. This was further supported by the linear parametric statistical methods frequently adopted in these studies, such as Pearson's *r* and linear regression models. Nonetheless, most of the included studies, except for the only one [4], have not explicitly reported conducting a non-linearity check, highlighting a broader methodological limitation in the field that warrants further attention.

In this meta-analysis, we adhered to the guideline outlined by Borenstein and colleagues [8]. For the meta-analytic results analyzed by pooling effect sizes (Pearson's *r*), the Fisher's *z* trans- and counter-transformation were applied for effect size interpretation. To ensure the analytical robustness of our findings, we employed various methods, including leave-one-out sensitivity analyses, subgroup analyses, meta-regression, publication bias assessment, and quality assessment [8]. The use of Pearson's *r* and meta-regressions is common in the meta-analytic research. Our utilization of these methods in the current meta-analysis aligns with the recommended approach of conducting meta-analysis using effect sizes based on the correlations [8,9] and is in line with previous meta-analyses that examined the relationship between sleep characteristics and other personality traits (e.g., aggression and self-control) [10–12].

We acknowledge the importance of considering alternative effect sizes, such as Spearman's *rho,* when examining the bivariate monotonic relationship, as they can capture non-linear, skewed, and exponential relationships observed in biological data [13,14]. However, the conversion from Pearson's *r* to non-parametric measures like Spearman's *rho* or Kendall's *tau,* or to empirically assess monotonicity is impractical without access to raw data, which is a recognized limitation in the meta-analytic research [15]. To the best of our knowledge, in the existing literature, the employment of mutual information (MI) and effective transfer entropy (ETE), is limited, despite their ability to capture both linear and non-linear dependencies. ETE can quantify the directional flow of information between two time-series variables while considering potential confounding effects [16,17]. Both methods require individual participant data (IPD) for computation, with MI quantifying shared information between two variables and ETE delineating directional information flow in time-series data. These approaches rely on individual observations or joint distributions that cannot be reconstructed from the summary statistics, such as Pearson's *r* or Spearman's *rho*. Therefore, linear methods remain the most practical and widely adopted approach in meta-analytic research. While we recognize the value of exploring non-linear relationships in future meta-analytic studies, we also stress the importance of advancing meta-analytic methodologies in sleep research, such as IPD meta-analysis or multiverse meta-analysis, which would allow for exploring non-linear effects, a robust assessment of heterogeneity by modeling participant-level variability, and a systematic evaluation of potential moderating factors [18–20].

In conclusion, we acknowledge the limitations associated with using linear parametric methods in the analysis of biological data. However, it is important to recognize that the current methodological approach adopted in our review remains the most parsimonious model given the constraints of meta-analytic summary data and the rigorous methods employed in conducting this review. The results presented have enhanced our understanding of the associations between personality

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traits and sleep and may have the potential to guide future research on personalized interventions to improve sleep. We encourage future empirical studies to provide more information on the data structure by conducting non-linearity check and using alternative statistical approaches to examine the relationship between personality traits and sleep characteristics. Furthermore, we advocate strongly for open science practices, including the sharing of raw data and the establishment of IPD data repositories, to facilitate more comprehensive and collaborative research efforts in the field.

Declaration of competing interest

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