Open science needs a standardized data format: suggestions for the field of psychoneuroendocrinology

Maria Meier[1,2], Christiaan H. Vinkers[3,4,5,6,7], Jens Pruessner[1,8], Milou S.C. Sep[3,4,5,6]

1. Department of Psychology, University of Konstanz, Germany

2. Child and Adolescent Psychiatric Research Department, University Psychiatric Clinics Basel (UPK), University of Basel, Switzerland

3. Department of Psychiatry, Amsterdam University Medical Centers Location Vrije Universiteit Amsterdam, The Netherlands

4.GGZ inGeest Mental Health Care, Amsterdam, The Netherlands

5. Amsterdam Neuroscience, Mood, Anxiety, Psychosis, Sleep & Stress Program, Amsterdam, The Netherlands

6. Amsterdam Public Health, Mental Health Program, Amsterdam, The Netherlands

7. Department of Anatomy and Neurosciences, Vrije University, Amsterdam, The Netherlands

8. Centre for the Advances Study of Collective Behaviour, University of Konstanz, Germany

Correspondence: Maria Meier (maria.meier@uni-konstanz.de)

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The field of science is in a stage of crisis. Questionable research practices like p-hacking and hypothesising after the results are known ('harking') combined with a publication bias towards positive over null findings (Munafò & Neill, 2016) have contributed to the replication crisis (Franco et al., 2014), critically limiting scientific progress (Moher et al., 2016). According to Kuhn's essay on the structure of scientific revolutions (1996), such a stage of crisis follows after too many anomalies have been observed during the phase of 'normal science', during which research follows established routines and paradigms. The above-named problems can be described as such anomalies which suggest that the established routines and paradigms are no longer sufficient to allow knowledge advance. The currently established routines and paradigms can be entitled as a practice of *closed science*, where researchers learn of research questions and hypotheses, the acquired data sets and methods, and the ensuing results only when given access to the published research article, which additionally is often hidden behind a paywall and does not necessarily include the original study materials and data. Yet, Kuhn argues that the stage of crisis is followed by a paradigm shift, where established routines, paradigms and assumptions are reviewed and revised to result in an improved model (Kuhn, 1996). In the face of the replication crisis, *open science* is the paradigm shift and model needed to allow for a self-correction of present anomalies, eventually contributing to improved and more valid scientific progress (Munafò et al., 2017).

Open science entails the idea and practice of ensuring that scientific knowledge, the research process, and the underlying data are accessible and transparent (Parsons, 2022). The overall goal is to promote self-correction and enhance the reliability and reproducibility of scientific results. This is of great importance, as scientific progress critically relies on robust findings (Nosek et al., 2022). While the replicability of findings in many areas is currently limited (Moher et al., 2016), the paradigm shift from *closed science* towards *open science* is well underway, as demonstrated by increasing efforts from researchers, funding agencies (e.g., the German Research Foundation, Deutsche Forschungsgemeinschaft, 2022; Dutch Funding Agency, https://www.nwo.nl/open-science; National Institute of Health, https://osp.od.nih.gov/advancing-the-promise-of-open-science/) and policymakers (e.g., the US government, https://tinyurl.com/4xrue2km; the European Union, https://tinyurl.com/ywhs3pjs). These efforts are being made to adopt and promote open science practices in research, and honor it in search committees for scientists by moving away from traditional quality assessments (e.g., the Declaration on Research Assessment [DORA], https://sfdora.org/). The practices encourage preregistering hypotheses and analysis plans (e.g., on the Open Science Framework, www.osf.io) and ensure that publications and the associated protocols, materials, code and data are fully accessible (Moher et al., 2016). Interested readers who thrive for more information and resources on open science practices and how to implement them may be referred to the resources overview provided in Meier et al. (2022), Box 1, and to other articles that provide comprehensible tutorials in this regard, e.g. on how to share files on the Open Science Framework (Soderberg, 2018).

The open science movement contributes to a sustainable use of resources, as the openly available data, code and materials can be reused by other researchers for further studies and explorations. Sharing these resources is especially helpful for fields like psychoneuroendocrinology (PNE), where data collection is resource-intensive and costly, and research questions are assessed in groups with often limited sample size. However, there are currently only limited systematic efforts in the PNE field to progress towards open science. For example, only a small proportion of studies in the field of PNE currently share their data and code openly (Meier et al., 2022). We here make the case that the introduction of a standardized data format for PNE is an important step forward to support researchers in making their research data openly available, thereby supporting a paradigm shift towards a broad implementation of open science practices in our field.

To be reusable for other researchers, research protocols, materials, code, and data need to be organized in a way that researchers can find and access, interoperate with, and understand them (cf. FAIR principles, https://www.go-fair.org/fair-principles/; Wilkinson et al., 2016). When it comes to research data being shared, this task is not trivial, especially with complex data where interpretation crucially depends on the context and details of acquired data (i.e. meta-data). In the field of PNE, biological rhythms and complex response dynamics (e.g., temporally lagged peak concentrations) are present which need to be taken into account when interpreting hormonal data (De Kloet, 2024). Related to this, a precise sampling schedule is necessary as timing will critically affect which conclusions can be drawn (Nebe et al., 2023). Beyond these design-related aspects, there are also demographic and psychometric variables that might modulate hormonal data (e.g., sex, age) (Strahler et al., 2017); likewise, technical specifications of the biochemical assays used to determine hormone concentrations from the sampled tissue or fluid are relevant when working with and interpreting a given dataset (Miller et al., 2013). Neglecting such information poses the risk of incorrect or imprecise inferences. The challenge thus lies in providing data and meta-data in an understandable and intuitive format (Wilkinson et al., 2016). This requirement might hinder PNE researchers from sharing and re-using data in the first place. When individual datasets are organized and labelled inconsistently between and even within research groups and laboratories, it is difficult to understand and work with datasets without investing considerable effort. Alternatively, the wrong interpretation of the data might follow. Consequently, researchers not directly involved in acquisition of the available data will require extensive time to familiarize themselves with unknown datasets and might even risk to arrive at wrong conclusions.

One solution to tackle these challenges is to provide well-commented analysis scripts alongside open data in the analysed format so that other researchers can reproduce published analyses and thereby gain a better understanding of the datasets provided. As of now, this solution is strongly encouraged as this enhances the reproducibility of reported results. On the long-term, the introduction of a standardized data format for PNE could further remedy these challenges. By agreeing on a standard data structure, a field can ensure that researchers can interpret and reuse data from others with low effort. A prominent example is the Brain Imaging Data Structure (BIDS) format which was introduced in 2015 and is used to share neuroimaging, electrophysiological, and behavioural data (https://bids.neuroimaging.io) (Gorgolewski et al., 2016; Poldrack et al., 2024). BIDS is community-driven and involves a standard for how to name and organize data files and meta-data and a nomenclature for naming variables in the data files (Oliver-Taylor et al., 2023; Poldrack et al., 2024). Furthermore, there are several technical support measures like web applications that help to transfer own data into the BIDS data structure (cf. https://bids.neuroimaging.io/benefits.html#software-currently-supporting-bids). Of note, the BIDS format is open for extensions that can complement the original structure that focused on imaging data (e.g. Pernet et al., 2019, https://tinyurl.com/5yxfjf9t). In a recent article, Russell Poldrack, one of the initiators of the BIDS format, states prominently in the headline 'Simply making data publicly available isn't enough. We need to make it easy — that requires community buy-in.' (Poldrack, 2024). Along that line, we are convinced that agreeing on such a structure and nomenclature together as a field could prove to be incredibly helpful in moving open science endeavours ahead in PNE.

Once established, a standardized data format could for example specify a directory tree, a nomenclature on how to name files and variables, and specifications on how to arrange and describe the dataset or code missing values. The structure could define mandatory information needed to understand the data (e.g., sampling time schedule, measurement unit), and compulsory information (e.g., coefficients of variations). Further, it could preset in which file format the data is shared to ensure accessibility and compatibility with commonly used software despite licences (e.g., text files with tab separated values [TSV]). Implementing new structures yet often comes at the cost of changing routines. This cost in time and effort might prevent individual researchers to adopt newly established formats. For this reason, the establishment of a standardized data format ideally goes hand in hand with the development of infrastructure and software that supports the individual researcher to arrive at the given format with ease and includes automated completeness and validity checks. This entails many advantages not only for the field of PNE, but also for individual researchers and research groups. For example, it ensures that others can work with the data without wasting considerable time and effort, thereby also reducing efforts for restructuring data for meta-analytic enquiries while lowering the threat of misinterpretation.

As a starting point for the PNE community to further develop and discuss this idea, we would like to point to the standardized data structure of the STRESS-EU database (Sep et al., 2024, Open Science Framework Project: https://osf.io/5mkhj/). The STRESS-EU database brings together (neuro)biological, physiological, and behavioural data of laboratory-based human acute stress studies in a standardized format. In this format, study related (e.g., sample size, acute stress test, time of day) and participant related information (e.g., age, diagnosis, cortisol values) are stored in separate standardized files which allow important meta-data to be provided comprehensibly. Templates for these 'study' and 'participants' files can be downloaded on the STRESS-EU database website (https://www.stressdatabase.eu/upload). While it needs to be openly discussed whether the structure of the STRESS-EU database is ideal for this endeavour, the database nevertheless showcases that it is possible to introduce a data format in the field of PNE, that allows the integration of multiple datasets despite of high heterogeneity in sampling schedules and other methodological factors (Goodman et al., 2017; Narvaez Linares et al., 2020).

We are convinced that the process of developing a standard data structure and supportive infrastructure should be discussed openly within the community, as this can ensure that different needs that depend on data type, phenomenon under study, population, or species are adequately met. Inspired by previous standard data structures (Gorgolewski et al., 2016; Sep et al., 2024), Table 1 provides a list of steps that may be needed to establish and implement a standard data structure in PNE. Once implemented alongside supportive infrastructure, it might likely lower the bar for researchers to share their data openly and FAIR, a practice that so far has not been adopted widely in our field (Meier et al., 2022). As outlined above, a standard data format might facilitate and promote successful data reuse by other researchers, which supports the sustainable use of resources and fosters collaborations and could move the field considerably ahead. While we acknowledge that not all data can be shared publicly without endangering anonymity of study participants, there are methods that could remedy this obstacle (cf., synthetic datasets, Quintana, 2020).

In conclusion, we believe that the PNE community is ready to develop and implement a standardized data structure for psychoneuroendocrine data. We invite the whole community to actively contribute to this timely endeavour and discussion by engaging in the open panel discussion that will be organised online at the ISPNE conference 2024 (https://ispne.memberclicks.net/2024-annual-meeting). We hope this comment sparks interest in creating a task force that will work on the implementation of such a standard data structure as well as on the necessary infrastructure to support researchers in this endeavour to ensure a successful adaptation. Interested readers are invited to reach out at the panel discussion or drop a e-mail to the corresponding author.

Table 1. Steps to establish and implement a standard data structure in psychoneuroendocrinology.

Step	*Goal*	*Realisation*
Initiate and form a task force	Initiate development of standard data structure and mobilize researchers from the field	Discussions and workshops at conferences and beyond Form task force with researchers from the field
Draft standard data structure and form consensus	Draft structure and gather and incorporate community feedback	Gather examples of data structures commonly used in the field and discuss content needed to understand and use psychoneuroendocrine data Draft initial specifications regarding directory structure, naming conventions and metadata requirements Gather community feedback and further input Revise data structure and publish resulting standard data structure
Provide support measures	Develop templates, tools and software that ensure easy and time-efficient adoption for researchers	Provide templates and standard operating procedures on how to share data using the standard data format Develop and publish web applications and software for data transformations and validity checks
Implement standard data structure	Encourage adoption of standard data format	Encourage publication of data in standard format alongside articles and provide open data batches alongside publications
Provide continuous support	Overlook developments and required updates	Ensure that support measures are supported long term and run smoothly Adopt specifications if needed

Declarations of Interest

None.

CRediT Author Contribution

Maria Meier: Conceptualization, Writing – Original Draft, Writing – Review & Editing; Christiaan Vinkers: Writing – Review & Editing; Jens C Pruessner: Writing – Review & Editing; Milou Sep: Writing – Original Draft, Writing – Review & Editing.

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