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Editorial

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The prospects of open science practices and large-scale collaborations for dream research

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Dream research has moved from a subjective and speculative field into the realm of scientific research by combining objective measures and controlled laboratory settings with subjective dream reporting. The most standardized and effective method to sample dreams throughout the night is a serial awakening paradigm, which involves waking participants multiple times to elicit dream reports [1]. However, this is highly resource-intensive both for the experimenters and participants. Consequently, much of our knowledge of dreams is based on small studies, often with sample sizes below 20 participants [2].

One research topic that has received considerable attention in recent years is the role dreams play in memory consolidation. As recent memories are often incorporated into dreams, it has been hypothesized that dreams may be involved in, or at least reflect, the ongoing memory consolidation processes during sleep [3]. With the first scientific study published in 1977 [4], several studies have since tried to probe dreams' role in memory experimentally. Commonly, a learning task is presented before sleep, testing memory recalls both before and after sleep. During sleep, several dream reports are elicited to quantify the incorporation of the task into dreaming and then the incorporation is related to memory performance. However, the results have been mixed, with several studies reporting null results, while others found a strong association.

To address these varied findings and better estimate the effect size dreaming of a task has on memory performance, Hudachek et al. completed a meta-analysis of 16 studies published between 1977 and 2021 [5]. The studies spanned declarative, procedural, and spatial memory tasks with dream reports collected both through awakenings as well as sleep onset and morning dream reports eliciting between 1 and 42 dream reports per participant.

Across the 16 studies (44 effects), Hudachek et al. found a significant and robust association between task-related dreaming and memory performance (0.52, $p < 0.001$) across all learning types. In the subset of studies that utilized polysomnography, there was a significant association between task-related dreams and subsequent memory performance in the 10 effects evaluated for NREM dream reports but not the 12 effects analyzed for REM dream reports. These findings suggest that dream content may signify sleep-dependent memory consolidation, primarily associated with NREM sleep [6].

This robust effect estimation is invaluable for designing future studies and highlights how underpowered the previous dream research literature has been. The previously average sample size of 25 only has 20% power to detect an effect of this size. Conversely, a study would need 60 participants per group to detect an SMD = 0.52 (Power = 0.8, two-tailed *t*-test), resulting in 240 nights of data collection for a two-group design with an adaptation night. Collecting such a sample size is often unfeasible due to both the high monetary costs involved and the personal costs incurred by the experimenter.

To reach the sample size sufficient for robust dream research, we will need to rely on several new strategies, many of which have already been spreading in other research areas due to the open science movement: (1) data sharing, (2) multilaboratory studies, (3) citizen science, (4) cohort studies, and (5) preregistrations.

Data sharing has become more widespread across many research areas and has become a requirement from many funding agencies, but it is still rare in sleep and dream research. However, there are several benefits to openly sharing data, including transparency and the ability to combine datasets to increase the sample size for analyses. It also means a more exhaustive analysis of datasets of all the data collected which usually goes beyond what is analyzed for a single study. Of course, precaution is needed to ensure that dream reports are only shared after removing identifiable details and with proper ethical approval for data sharing.

Another strategy has come in the form of multilaboratory studies, initially often focused on replication efforts such as the Open Science Collaboration [7] and ManyLabs Studies [8]. In a multilaboratory study, the same study design is applied across multiple laboratories so that with modest costs for each laboratory, large sample sizes can be collected. Compared to sharing data after the collection, it offers the advantage of a standardized study design, making it easier to combine data across different studies. Additionally, it allows for studying the variance of the effect across laboratories.

Instead of eliciting multiple laboratories, one can also extend data collection beyond the sleep laboratory: while citizen science—i.e.

involving the public in data acquisition, but increasingly also in the study design and analysis of the resulting data—have a considerable tradition in the natural sciences, neuroscience only recently begun to involve citizen scientists [9]. This development was accelerated by innovations in the consumer market of sleep trackers, enabling individuals to investigate their physiology with affordable but increasingly reliable technology. Open hardware and software solutions to record, modulate, and analyze sleep outside academic research settings further broaden the opportunities for nonprofessionals to engage in citizen neuroscience [10].

A notable example of citizen science activities that include sleep measurements is the "Quantified Self" (QS) movement, where individuals without formal academic positions or training longitudinally log and analyze behavioral and physiological data with consumer devices, but increasingly also with dedicated research equipment [11, 12]. Adding dream questionnaires to the extensive and densely sampled longitudinal measurements of quantified selfers and other citizen scientists would allow generating of large dream research datasets with relatively modest funding investments.

While sleep and dreaming are best conceptualized as states of consciousness, they can also be studied from a trait perspective: by adding questionnaires such as the Mannheim Dream Questionnaire [13] to large study cohorts, associations between aspects of dreaming and neurophysiology can be studied with relatively modest additional resources. For example, the EU COST Action CA18106 *The Neural Architecture of Consciousness* has generated datasets comprising dream trait data in addition to several neuroimaging modalities from $n > 300$ participants each, for which first analyses of dream topics have already been performed, e.g. [14],. While elucidating the association between memory consolidation and dreaming typically requires dedicated experimental set-ups that cannot easily be included in cohort studies designed for a different purpose, they provide large-n opportunities for analyses that might complement more controlled experiments with smaller sample sizes.

Lastly, preregistrations should be used to make sure that the data that is collected will be analyzed in a robust and rigorous manner. While preregistrations generally prevent questionable research practices such as p-hacking and the file drawer problem, they might be particularly beneficial for dream studies, given the typically small samples sizes in combination with rich qualitative and quantitative data that can give rise to a multitude of variables and combinations thereof, thus potentially inflating research degrees of freedom. A particular case of preregistrations, the registered reports, additionally allows reviewer feedback before data is collected. We are conducting the first Registered Report in dream research collecting data on dreaming and memory consolidation with a planned sample size of 92 participants [15].

Dream research will continue to give us valuable insights into our brains during sleep; however, to be able to collect high-quality datasets that will provide us with enough power to analyze the effects we are interested in, dream researchers will have to embrace open science practices including data sharing and study preregistrations, start conducting multilaboratory studies and engage citizen scientists in large-scale home studies.

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