Final Scientific Report - January 2024

Project title: *Mentation report analysis across distinct states of consciousness: a linguistic approach*

Project number: 091/2020

PI: Prof. Giulio Bernardi and Prof. Michele Bellesi

Aims

Dreams are subjective experiences generated during sleep, a state in which the individuals are disconnected from the external environment and have no voluntary control over their experience. Indeed, dreams are thought to reflect an internal processing of previously acquired memories and beliefs, which may be in part concealed to the waking consciousness.

Preliminary evidence indicates that the peculiarities of individual oneiric experiences may be quantitatively measured through the application of natural language processing (NLP) methods to the analysis of dream reports collected in the morning, upon awakening. Specifically, the main objective of the present study is to investigate the potential value and feasibility of big-data collection and automated analysis of dream reports based on the most advanced tools of computational linguistics, including, amongst others, word embedding, clustering analysis, and graph analysis. Central to the project arethe creation of an open-access repository (i.e., a dream-bank, where verbal reports of dream conscious experiences will be collected) and the development of tools (software, algorithms) for extracting quantitative information suitable for further investigations with a potential translational value.

Methods

Participants. We planned the recruitment of up to 300 healthy Italian native language speakers aged between 18 and 70 years. Only subjects with normal sleep/wake patterns, six to eight hours of sleep per night, and no diagnosis of sleep-related problems or of any other pathological condition that might have compromised their brain functioning and behavior were included in the study. Subjects who, at the time of the study, were taking medications that could have affected sleep patterns, brain functioning, or behavior were excluded. Similarly, we excluded subjects who had a history of alcohol and drug abuse in the last six months before the study. Since pregnancy and breastfeeding may affect sleep patterns, women who were pregnant, were planning a pregnancy, or were breastfeeding at the time of the study were not included. The study was conducted under a protocol approved by the Joint Ethics Committee of the Scuola

Normale Superiore and the Scuola Superiore Sant'Anna (#11/2020). All volunteers signed a written informed consent form before taking part in the studies and retained the faculty to drop from the study at any time.

Procedures. Participants were first asked to fill out an anamnestic questionnaire and questionnaires measuring attitude toward dreaming, trait anxiety levels, vividness of visual imagery, proneness to mind-wandering, subjective sleep quality, subjective circadian preference, and daytime sleepiness. Then, they were asked to record a report of their last dream experience each morning upon awakening for two weeks. Moreover, at pseudo-random times during the day, participants were also contacted via cell phone text and asked to record everything that was going through their mind up to 15 minutes before they started the recording. During the two weeks of the study, participants had to wear an actigraph (MotionWatch-8, Camtech), a non-invasive method to track their sleep-wake pattern and the overall quality of their sleep by monitoring rest-activity cycles. A subgroup of volunteers also received a portable electroencephalographic system (DREEM) and were asked to wear it each night, at home, throughout the whole experimental phase of the study. At the end of the two-week period, during the final visit, all participants underwent a neuropsychological assessment aimed at evaluating different cognitive abilities, including verbal and visuospatial memory, vulnerability to interference , semantic memory and connected speech.

Data preprocessing. Oral reports were automatically transcribed. One of the researchers verified the correspondence between the voice data and the transcriptions and replaced sensitive data included in the reports with codes. Then, textual data were manually cleaned of any information that did not directly concern the experience (e.g., subjects' comments and digressions). We classified each morning report provided by the subjects as: dream experience (DE) if the verbal description included at least one reference to any kind of semantic content; dream experience without recall (DEWR; or 'white dream') if the subject referred the perception of having dreamt but could not recall any feature of the experience; no dream experience (NDE), if the subject woke up with the feeling of not having dreamt.

Organization of the database and preliminary analyses. All the collected dream and waking reports are being stored along demographic information such as age, sex, and education, and psychometric, cognitive, and electroencephalographic measures. All data were anonymized. To demonstrate the potential value of our database, which we named 'Somnieve', we performed two sets of analyses that we plan to publish in peer reviewed scientific journals. The database will be released to the scientific community contextually to the publication of the articles.
The first set of analyses was performed to investigate the individual determinants of dream recall frequency (DRF). In particular, we employed a multiple regression analysis including DRF as the predicted variable and the following predictors: age, sex, education, vulnerability to interference, verbal memory, visual memory, trait anxiety levels, subjective sleep quality, subjective circadian preference, visual imagery, and proneness to mind wandering. A second multiple regression model was performed with the inclusion of sleep-wake patterns measured through actigraphy.

The second set of analyses aimed to quantify and analyze dream content features. To this aim, we trained an LSTM recurrent neural network on a subset of dreams (n=823), which were scored by four raters on 16 semantic features of interest. In particular, the following features were taken into account: references to experimental procedures, metacognitive processes (abstract thoughts or reasoning), visual experiences auditory experiences, tactile experiences, valence, arousal, bizarreness (illogicality, strangeness or discrepancy of the events), social interactions, movement, space (details regarding the environment), change of setting, time (chronological aspects of the events), body (references to any body part and bodily function or instinct), limitations of freedom (elements that restricted or could restrict characters' freedom of action within the dream), degree of active involvement of the dreamer within the events. A cluster analysis was then performed on the whole database and correlations between dream features and individual factors were explored.

Results

Collected sample. We recruited a total of 220 participants (18-70 years of age, 94 males). Of these, 50 subjects used the DREEM device (24-44 years of age, 23 males). Of note, in spite of our efforts to reach the originally planned sample size, we encountered increasing difficulties in recruiting volunteers during the project's development. Apparently, the peak of the pandemic eased our recruitment since individuals had more free time and were more willing to take part in our research. With a return to normal daily rhythms, we observed an increase in the number of individuals who reported to be too busy or too anxious/worried to participate in the experiment. Nevertheless, we consider the reached sample size highly satisfactory. Indeed, our dataset represents the largest, multimodal dream database ever collected in terms of number of participants and included measures/indices.

Preliminary analyses. Preliminary analyses were conducted on data obtained from 161 subjects (66 males, age range 18-65 years). The main obtained results are described below. Of note, we are currently extending our analyses to the full sample of participants and are preparing two manuscripts that will be based on the full sample results. We plan to submit the first manuscript, on the individual predictors of dream recall, by the end of March 2024, and the second manuscript, on the analysis of dream content, by the end of October 2024.

The predictors of morning dream recall. The multiple regression model revealed significant effects ($p < 0.05$, FDR correction) for age, attitude toward dreaming, vulnerability to interference, verbal memory, and proneness to mind-wandering. The additional analysis including actigraphy-derived measures, also showed a significant association of dream recall with advanced sleep onset and offset times (advanced sleep phase). Of note, changes in sleep patterns appeared to explain the previously observed effect of age on dream recall, as this association became non-significant. In contrast with previous studies, we did not find a prediction effect of biological sex. However, we found a significant association between sex and attitude toward dreaming, as women tended to have a higher interest in dreams than men ($p <$

0.05). Therefore, the observed effect of sex could be actually explained by differences in attitude toward dreaming.

The quantitative analysis of dream content. The LSTM classifier showed an optimal scoring agreement with human raters for most considered dimensions, with few exceptions that are incorporation of experimental procedures, auditory perception, valence, social interactions, and active vs. passive behavior of the dreamer. Of note, though, even for three of these dimensions (except for experiment incorporation), the goodness of agreement was moderate-to-strong, according to Spearman's correlations between LSTM scores and human scores ($r > 0.4$). The cluster analysis allowed us to map the relationships between the selected semantic features but did not reveal any clear dream clusterization. Indeed, dream features appeared to change along a continuum only partially explained by word count. We then investigated the potential predictors for a subsample of dream features: dream valence was predicted by trait anxiety during wakefulness ($p < 0.05$, FDR corrected), dream bizarreness was predicted by subjective sleep quality, and the amount of visual experience was predicted by general attitude toward dreaming.

Discussion

Within this project we created *Somnieve*, a multimodal, open-source database collecting dream reports along with demographic information and psychometric, cognitive, and electroencephalographic measures obtained from the healthy Italian adult population. *Somnieve* currently includes 220 subjects who provided more than 2,500 verbal reports. As such, *Somnieve* represents the largest database of dreams collected using a standardized, prospective experimental protocol ever created. Moreover, while most existing databases only include the dream reports along with basic information such as age and sex, *Somnieve* includes a large number of psychometric, cognitive, and physiologic information. Crucially, the *Somnieve* database is expandable. Thus, even if we did not reach our original goal of recruiting 300 participants, we will be able to achieve this goal through further data collection performed by our or other laboratories. The database may be also expanded to include pathological populations, to investigate how dream changes in non-physiological conditions and thus evaluate their potential clinical diagnostic or prognostic value.

To demonstrate the potential applications of *Somnieve*, we performed two sets of analyses aimed at exploring the individual determinants of dream content and recall. We found that dream recall frequency is predicted by attitude towards dreaming, vulnerability to cognitive interference, verbal memory, tendency to mind wandering, and sleep onset/offset times. Our results support in part previously published observations, but also extended and complemented them with new, original findings. In addition, we created a tool for the reproducible classification of dream content, which achieved a performance similar to that of human raters. This tool allowed us to explore dream features in over 1,300 dream reports and to explore individual factors associated with specific dream contents. We found that higher trait anxiety levels are associated with more negative emotional valence, in line with the continuity hypothesis of

dreams, higher attitude towards dreaming is associated with more visual elements in oneiric experiences, and lower sleep quality is associated with higher dream bizarreness, independent of emotional valence.

Open, multimodal databases like *Somnieve* will be crucial to improve reproducibility in dream research and thus identify the individual determinants of dream content and DRF in physiological conditions, as well as quantify their possible pathological alterations. Importantly, our group received in 2023 a grant from the *Italian Minister of University and Research* to explore possible alterations of dreams in pathological conditions. The *Somnieve* dataset will be used as a reference for our investigations, and the BIAL Foundation will be duly acknowledged in all publications stemming from this additional research.

Deviations from research plan

In our original proposal, we indicated a target sample size of 300 volunteers. However, due to increasing difficulties in participants' recruitment during the project's life, we have been able to recruit a total of 220 participants, corresponding to ~73% of the planned participants. As noted above, even if we did not reach to planned sample size at the end of the project, the database could be further expanded in the coming years both by our laboratory and, potentially, by independent research groups. To ensure the possibility of further expanding our database, we asked the Ethical Committee to extend the project duration to 2027.

As noted in our previous scientific reports, the original research plan was amended to include one additional questionnaire (attitude toward dreaming questionnaire; Bulkeley and Schredl, 2019) and one cognitive test (Wechsler Adult Intelligence Scale vocabulary subtest; Wechsler, 2008) . An additional amendment was subsequently requested to extend the age range of potential participants to 70 years of age (from the previous limit of 65 years) and extend the project's duration, as indicated above.