NeuroImage 124 (2016) 1182–1187

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

# OMEGA: The Open MEG Archive

Guiomar Niso [a,1], Christine Rogers [a,1], Jeremy T. Moreau [a], Li-Yuan Chen [a], Cecile Madjar [b], Samir Das [a], Elizabeth Bock [a], François Tadel [a], Alan C. Evans [a], Pierre Jolicoeur [c], Sylvain Baillet [a,*]

[a] McConnell Brain Imaging Centre, Montreal Neurological Institute, McGill University, 3801 University St. Montreal, QC H3A 2B4, Canada
[b] Douglas Mental Health University Institute, 6875 Boulevard Lasalle, Verdun, QC H4H 1R3 Canada
[c] Institut Universitaire de Gériatrie de Montréal, Université de Montréal, Département de psychologie Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, QC H3C 3J7, Canada

ARTICLE INFO

*Article history:*
Accepted 10 April 2015
Available online 18 April 2015

*Keywords:*
MEG
Open-access
Database
MRI
EEG
Electrophysiology

ABSTRACT

In contrast with other imaging modalities, there is presently a scarcity of fully open resources in magnetoencephalography (MEG) available to the neuroimaging community. Here we present a collaborative effort led by the McConnell Brain Imaging Centre of the Montreal Neurological Institute, and the Université de Montréal to build and share a centralised repository to curate MEG data in raw and processed form for open dissemination. The Open MEG Archive (OMEGA, omega.bic.mni.mcgill.ca) is bound to become a continuously expanding repository of multimodal data with a primary focus on MEG, in addition to storing anatomical MRI volumes, demographic participant data and questionnaires, and other forms of electrophysiological data such as EEG. The OMEGA initiative offers both the technological framework for multi-site MEG data aggregation, and serves as one of the largest freely available resting-state and eventually task-related MEG datasets presently available.


## Introduction

The benefits of data sharing in neuroimaging research are hard to dispute. However multiple notable challenges, ranging from ethical considerations to technological hurdles, have meant that only a small proportion of all acquired data is currently being made openly available (Poline et al., 2012). In contrast to some other neuroimaging modalities, efforts at creating multi-site databases for open sharing of magnetoencephalography (MEG) datasets have been rather limited. While several research initiatives have conducted large-scale analyses of MEG data within specific target populations (Fernández et al., 2012; Huang et al., 2014; Stefan et al., 2003), only a handful of fully open resources currently exist in the field. One of the few open initiatives in this regard has recently been spearheaded by the Human Connectome Project, with the planned inclusion of one hundred MEG participants into the ConnectomeDB (Larson-Prior et al., 2013). Nevertheless, akin to other imaging modalities, there is still much to be gained from open sharing of ever-growing MEG datasets in the greatest variety of task settings and populations. Consequently, we have undertaken the implementation of infrastructure to facilitate multi-site sharing of MEG data.

The Open MEG Archive (OMEGA) is an open-neuroscience initiative piloted by the McConnell Brain Imaging Centre (BIC) of the Montreal Neurological Institute (MNI) at McGill University in conjunction with the Université de Montréal. It represents a first endeavour to create a centralised repository to systematically organise MEG, structural MRI, and electrophysiological data for open dissemination. Great emphasis is placed on data harmonisation, particularly in terms of collection and curation of participant information, neuroimaging acquisition parameters, and quality control procedures. This open repository presently consists of de-identified datasets contributed from an increasing number of studies at both founding institutions, in compliance with the prescribed ethical data sharing standards of those studies. A unique databank policy regulating property, access, and sharing of data housed in OMEGA has been established and approved at both institutions (available from the OMEGA front page). The OMEGA project is expected to grow and become inclusive of other contributors and data modalities, including other forms of electrophysiological data.

The Open MEG Archive is built upon the LORIS neuroimaging platform, a web-based open-source data management system initially developed at the MNI for longitudinal multi-site MRI studies (Das et al., 2012). We have contributed a number of customisations that extend core LORIS database functionality for handling of MEG data, including its characteristic multidimensional time series and metadata. Although presently dimensioned for contributions from the two founding institutions, integration of future data contributions from additional sites is easily supported by LORIS' scalable architecture for

* Corresponding author at: McConnell Brain Imaging Centre, Montreal Neurological Institute, McGill University, Room NW107, 3801 University, Montreal, QC H3A 2B4, Canada.
*E-mail addresses:* guiomar.niso@mcgill.ca (G. Niso), christine.rogers@mcgill.ca (C. Rogers), jeremy.moreau@mail.mcgill.ca (J.T. Moreau), li-yuan.chen@mail.mcgill.ca (L.-Y. Chen), cecile.madjar@gmail.com (C. Madjar), samir.das@mcgill.ca (S. Das), elizabeth.bock@mcgill.ca (E. Bock), francois.tadel@mcgill.ca (F. Tadel), alan@bic.mni.mcgill.ca (A.C. Evans), pierre.jolicoeur@umontreal.ca (P. Jolicoeur), sylvain.baillet@mcgill.ca (S. Baillet).
[1] Both authors contributed equally to this work.

http://dx.doi.org/10.1016/j.neuroimage.2015.04.028
1053-8119/

distributed data sharing (Das et al., 2016-in this issue). In this initiative, we see a significant opportunity to incorporate structure for the entire electrophysiology community: OMEGA is a proposition to enable data harmonisation in a field marked by a variety of data formats and recording scales (MEG, EEG, cell and field recordings), although with relatively similar principles (wideband time series recorded on arrays of channels).

## Objectives of the database

OMEGA was designed with the dual intent of creating greater standardisation of MEG acquisition procedures and record-keeping, as well as facilitating sharing of data within the larger scientific community. One primary objective of the project is to collect and curate resting-state data in a large sample of healthy participants in order to establish normative standards of brain activity (following source imaging on individual anatomy, followed by group registration) with relation to standard demographic factors (e.g. age, gender, education). Such normative variants are not established yet in MEG, and harmonising data from multiple studies could facilitate high-powered investigation of related research questions. In particular, OMEGA could enable the identification and discovery of new markers of neurological or psychiatric conditions by comparing clinical subsamples or single patient data to large groups of matched healthy participants. In its current implementation, the repository aggregates data acquired at the BIC and the Université de Montréal, which includes a growing number of datasets from previous and ongoing studies. At both institutions, researchers collecting data via the MEG platform are prompted prior to each new session as to whether they are willing to contribute their recorded datasets and if so, participants are consented specifically for inclusion in OMEGA.

## Available datasets

The OMEGA repository currently houses resting-state MEG and T1-weighted anatomical MRI data (primarily for optimal source imaging) from 97 participants at one or more timepoints (total of 140 sessions). These datasets were gathered from a total of eight past and ongoing studies. At present, OMEGA mainly includes healthy participants; however we have recently commenced efforts to collect clinical samples within the database, starting with two concussion and eight amusic patients from ongoing studies. Basic demographic information such as age and gender are available for all participants. Additional non-identifying demographic characteristics are available for select participants on a per-study basis. A summary of available data is presented in Figs. 1–2.

All MEG datasets within the OMEGA database presently offer both raw scanner data in vendor-specific formats, as well as processed data which has undergone some initial pre-processing in Brainstorm (Tadel et al., 2011). Anatomical MRIs (T1 volumes) are also available for most participants in DICOM, MINC, and NIfTI formats. MEG datasets presently include at least two minutes of empty-room data, and runs of resting-state recordings, each of a minimum of 5 minute duration. Following MEG good-practice recommendations (Gross et al., 2013), empty-room recordings are made available to capture environmental noise conditions at the time of data collection, and are crucial for subsequent offline data pre-processing. In most cases, resting-state data were collected with participants sitting upright with their eyes open. Such environmental details and acquisition parameters for each session are captured within the database in custom MEG parameter forms, which are stored and curated jointly with the imaging data. Task-related datasets, and datasets having already undergone some degree of analysis (i.e. including source image volumes) can also be added to OMEGA.

MEG data at the BIC and the Université de Montréal are collected on identical CTF whole-head MEG systems (VSM MedTech Inc., Coquitlam,

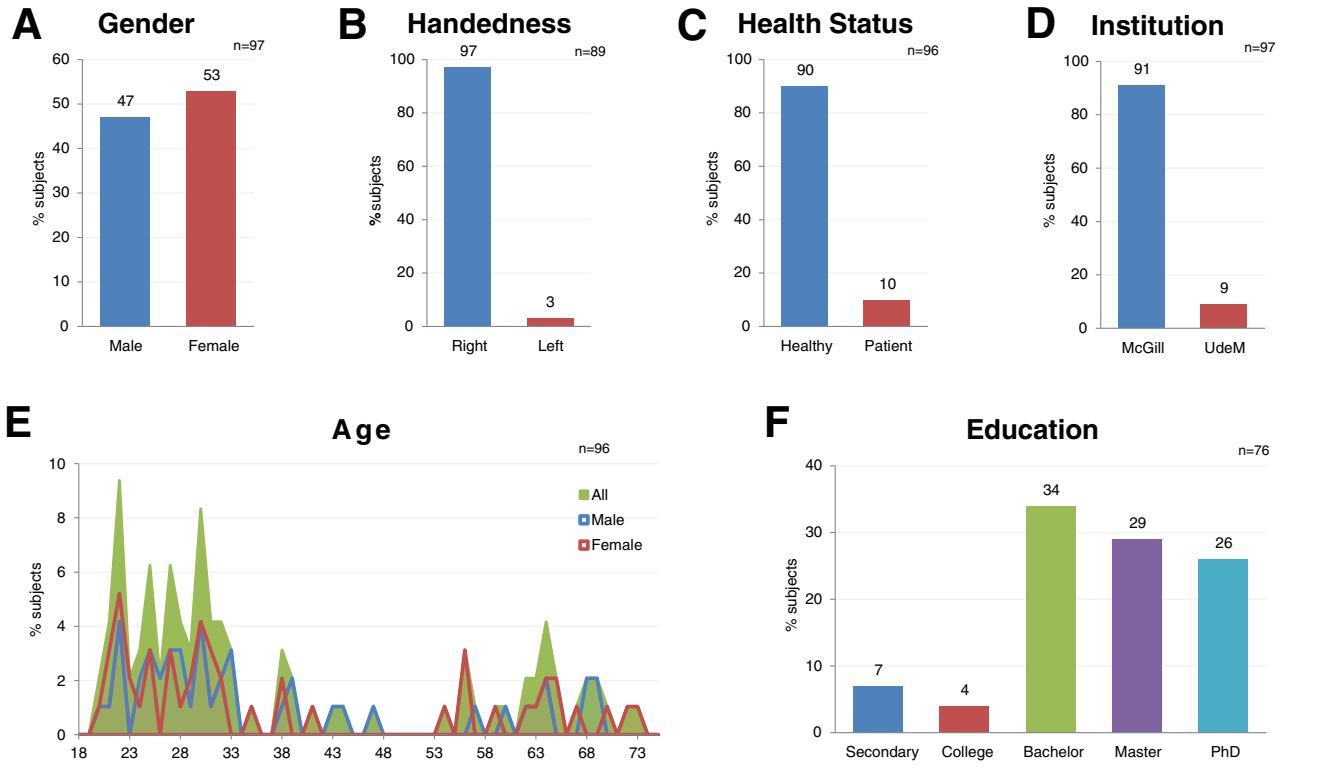


**Fig. 1.** General demographic information for participants included in OMEGA. A) Gender. B) Handedness. C) Health status: Healthy or Patient. The patient subsample currently includes two concussion individuals with injury less than six months prior to the recording, and eight amusic subjects. D) Institution where the recording was acquired. E) Age distribution (average: 37.7 ± 21.5 years). F) Education.

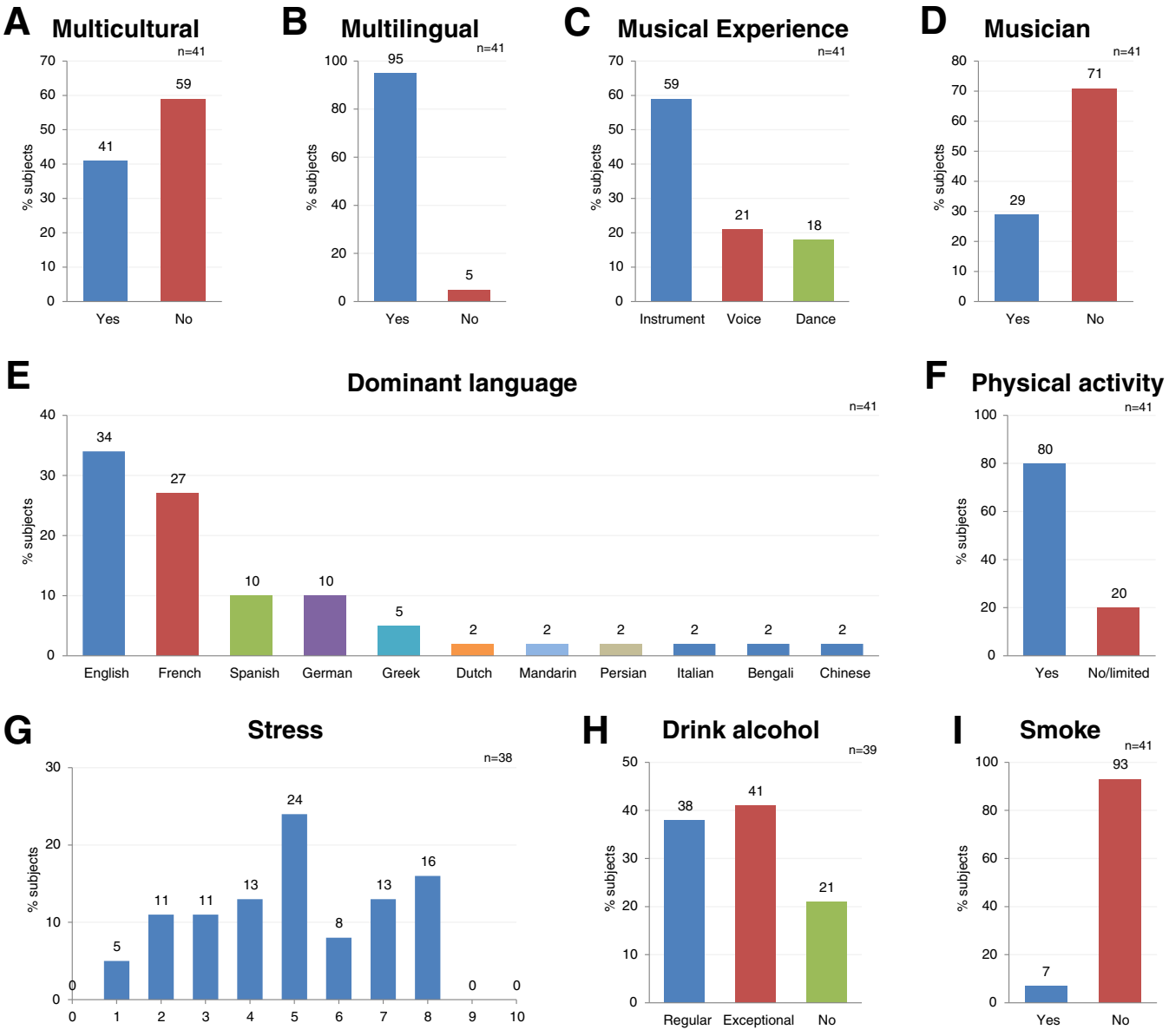


**Fig. 2.** Cultural and lifestyle information for participants included in OMEGA. A) Self-identification as bicultural or multicultural (i.e. growing up with parents or relatives from different cultures, or having lived in different cultures for extended periods of time). B) Multilingual, on average 2.9 ± 1.1 languages spoken/person. C) Musical experience in relation to instruments, voice, and dance experience, on average 2.1 ± 1.3 instruments played/person. D) Self-identification as musician or not. E) Dominant language. F) Physical activity frequency on a two-point scale ("no or very limited physical activity", or "some physical activity"). Participants who reported practising some physical activity practised on average 3.0 ± 1.6 times a week. G) Self-reported stress levels on a ten-point scale where 0 = no stress, and 10 = extremely high stress (average: 4.9 ± 2.1). H) Frequency of alcohol consumption. "On exceptional basis" refers to less than 4 times a month and in relatively low quantity. I) Smoker or non-smoker status. For smokers, onset of smoking was 13.0 ± 3.0 years on average and most frequently reported number of cigarettes smoked per day was in the 1–5 cigarettes/day range.

BC, Canada) consisting of 275 first-order axial-gradiometer coils and third-order gradient correction to subtract background interferences, with passive magnetic shielding. Fiducial and head shape information obtained through 3D digitisation during subject preparation, as well as head motion information collected via head-positioning coils, is available for all participants. Together with all MEG datasets, electrooculography (EOG) and electrocardiography (ECG) data are available. For a subset of participants, electroencephalography (EEG) data are available with digitised 3D electrode positions.

In addition to imaging data, a comprehensive set of non-identifying individual characteristics is collected for every new participant, and is available for a portion of participants currently entered in the OMEGA database (see Figs. 1–2). This information is collected via a general screening questionnaire adapted from Coffey et al. (2011). This questionnaire provides researchers with basic information about participants, with questions ranging from participant background and demographic details to current health status and hobbies.

As further discussed below, all participants are assigned a pair of unique IDs, which are identical across all studies in OMEGA, to facilitate reporting which participants' data were used in the analyses, and hence, reproducibility. Data from individual participants are tagged with the dataset from which they originate, but as the database was constructed with the intention of cross-study analyses, dataset-wide unique IDs would not have offered a practical level of granularity. Instead, given the focus on individual participants and timepoints, a participant-centric unique identification scheme was selected.

## Quality assurance procedures

Quality assurance features are provided by the LORIS platform for MRI, behavioural, and clinical data (Das et al., 2012). This innate functionality has been extended for the Open MEG Archive in order to handle MEG data. Metadata pertaining to a number of acquisition parameters are automatically extracted from the headers of raw MEG data files and stored in the database. These metadata are complemented with detailed information entered in a structured MEG quality control form stored alongside the imaging dataset. This form is completed for each run of an imaging session and captures information such as levels of noise, lists of bad channels, estimations of head movements, levels of typical system artefacts (e.g. power-line contamination, or artefacts from stimulation delivery) and subject artefacts (e.g. eye movements, muscle tension). EEG, EOG, and ECG quality control information is also entered into this form when available. Quality control information is visible to all users, although editing this information requires special user permissions. These permissions are typically granted to select members of the research team originally responsible for collecting the dataset, or in some cases a knowledgeable expert or database curator who may perform subsequent data validation and review.

In addition to the quality control form completed for every run of a MEG session, an additional parameter form is also provided per session. This form is designed to collect additional notes such as parameters not automatically extracted from the headers of the raw MEG data files and other general acquisition-related details and comments. It contains such information as the MEG instrument used for acquisition, sampling rate, details concerning digitised scalp points, and specifications of on-line filters applied. Both the quality control and parameter forms were designed according to good MEG practices (Gross et al., 2013) and constructed in a structured manner so as to optimise data quality and completeness—ultimately enabling the possibility of querying each field. Our objective with these forms was to encourage greater

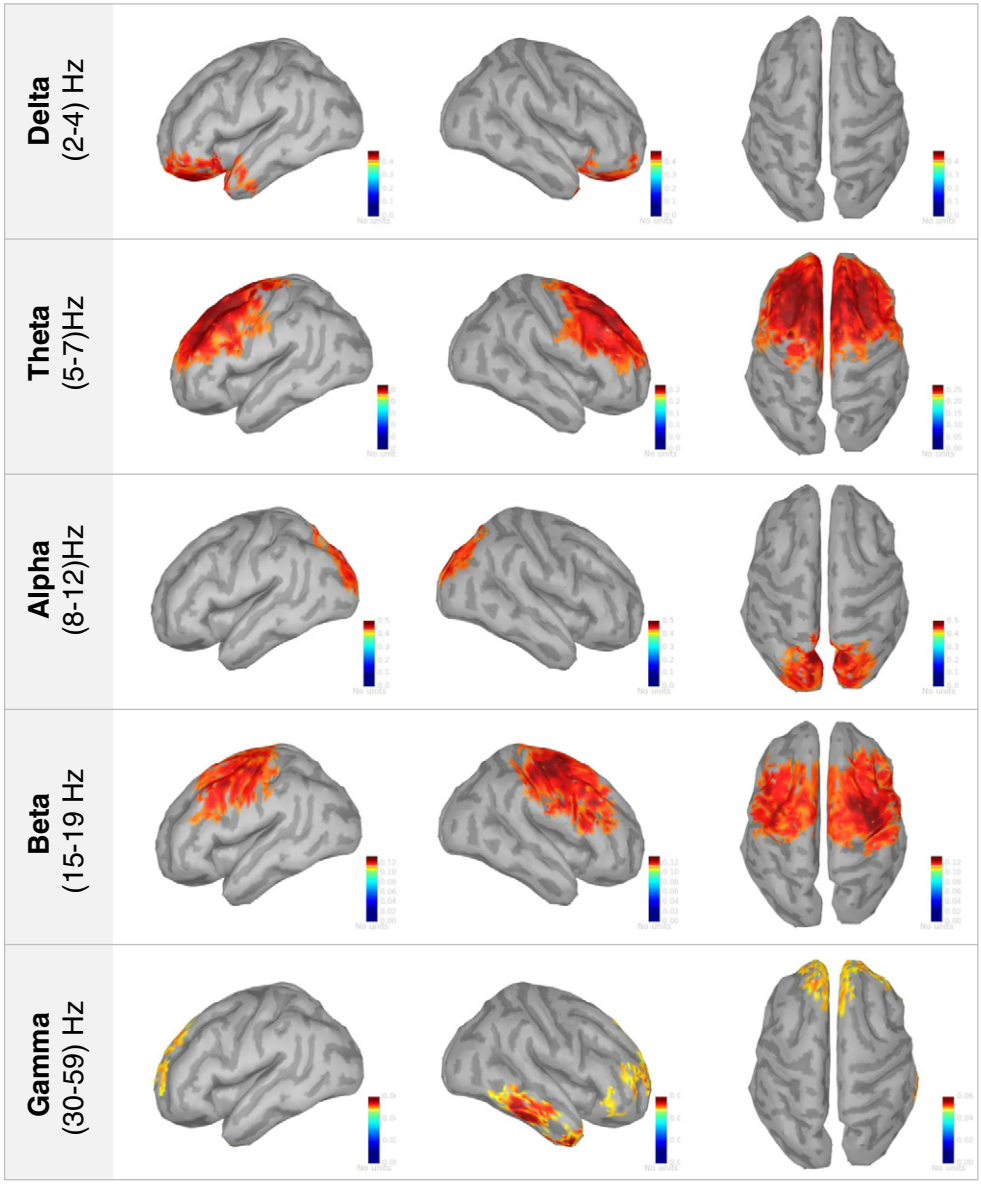


**Fig. 3.** Average relative power of ongoing cortical activity in typical electrophysiological frequency bands. Averaged relative power spectral density over 46 healthy participants. Head surfaces were imported from the segmented MRI files and used for MEG source analysis. Cardiac and blink artefacts were detected using ECG and EOG signals, and corrected for. MEG head and source modelling consisted of overlapping spheres and weighted minimum norm estimates, respectively (Baillet et al., 2001). Finally, relative power spectrum densities were computed within each frequency band, and each participant's individual results were projected onto the COLIN27 default anatomy to obtain the group average. All MEG preprocessing and analyses were performed using Brainstorm (Tadel et al., 2011).

standardisation of MEG quality control and acquisition parameter documentation, hence facilitating subsequent meta and multi-site analyses.

## Data access and availability

The OMEGA contents are made available to anyone who requests access through omega.bic.mni.mcgill.ca (see "Request OMEGA Account"). New account requests are manually reviewed, but registration is open to all, and registered users have full access to all shared data. The registration process was implemented to allow the gathering of basic contact information and to limit automatic harvesting of data. Contact information would be used to notify users in the eventuality that changes or additions were made to a dataset. No data usage agreements are enforced, but we ask that the OMEGA database and researchers responsible for gathering a particular dataset be cited and/or acknowledged when the data is used in a publication.

Data in OMEGA are organised by participant rather than by study or cohort dataset, due to LORIS' participant-centric architecture. This organisation facilitates longitudinal and heterogeneous data collection, and helps ensure that data of a given participant originating from different studies are not analysed as separate individuals in subsequent meta-analyses. It also has the added advantage of avoiding unnecessary duplication of anatomical MRIs and demographics data. Data are tagged with the name of the dataset they originate from in order to allow tracing of their provenance. De-identification is undertaken prior to insertion into the database, and each participant is assigned two unique identifiers as implemented by LORIS (Das et al., 2012). The first of these identifiers is the Project Study Centre ID (PSCID) which is assigned at the time of insertion and consists of a three-letter code abbreviating the acquisition site followed by a 4-digit number indicating participant registration sequence. For example, the first participant registered from the MNI site is assigned the PSCID "MNI0001". This ID allows for researchers to identify participants in their reports, while participants' identities remain available only to the principal investigator of the experiment. The second identifier assigned to each participant is the Data Coordinating Centre ID (DCCID), which is a randomly generated six digit number (e.g. 129373) that is used internally by LORIS.

The large size of datasets handled by the database presents some technological challenges. For anatomical MRI datasets, LORIS implements a browser-based Imaging Uploader module. However, uploads of larger time-resolved MEG datasets are currently handled manually by the administrators of the database. While efficient and sufficient for current needs, the process requires some degree of technical expertise. Accordingly, we have been working on various solutions to provide a friendlier user experience. This has entailed the development of an open source cross-platform desktop upload client that allows for encrypted and resumable transfer of large datasets into the database (Moreau, 2014). Downloads are handled through the database's web interface, whereby MEG and MRI datasets can be accessed for individual participants. Functionality to query for and download multiple datasets at once is available in LORIS, and is in the process of being tested for MEG datasets.

## Contributing data

While the Open MEG Archive is an initiative piloted by McGill University and the Université de Montréal, the technological infrastructure to integrate datasets from other centres or sites is already in place, and requests to contribute MEG data are welcomed. The modular nature of the database means that MEG data acquired on machines from all manufacturers (CTF, Elekta, etc.) can easily be accommodated. Participant consent and ethics approval from local research ethics boards/institutional review boards are required before any data can be uploaded. The consent forms and databank policy used for OMEGA are available on the database's website. Contributors must also ensure that all data are de-identified and agree that their datasets be made freely available without restrictions. Use of our set of standardised forms outlining general MEG acquisition parameters, quality control criteria, and participant demographics is also strongly suggested, but not an absolute requirement.

## Future outlook

The database is presently under the management of the core MEG research group at the BIC, with support from the LORIS development team. It is a pilot project designed to explore the challenges of, and develop solutions for standardised multi-site MEG data sharing. A major long-term goal of the project is to establish standard MEG variants (at the sensor or source levels) of brain activity and brain connectivity (Tadel et al., 2011; Niso et al., 2013) in a large population of healthy participants with relation to standard factors (e.g. age, gender, standardised behavioural test scores). One potential application would be the identification of new electrophysiological markers of abnormal brain activity in patients affected by neurological or psychiatric conditions. Possibilities in this regard are exemplified in Fig. 3, with the illustration of average power of cortical activity in selected frequency bands in a subsample of 46 healthy participants. Concerning management and maintenance, it is planned that in the longer term this project will be integrated into a larger multimodal BIC initiative to centralise and share the multimodal data acquired within the institution. Large-scale open data has already demonstrated the potential to exert a transformative influence in some fields of science (Collins et al., 2003), and we believe that every step towards this ideal within the MEG/electrophysiology and neuroimaging community, is a step in the right direction.

## Acknowledgments

The Open MEG Archive was initially supported as a Strategic Initiative of the Quebec Bioimaging Network (QBIN). The authors are thankful for the contributions of MEG scientists Therese Lennert, Esther Florin, Maryse Thomas, Benjamin Morillon, Philippe Albouy, Peter Donhauser and Eva Chadnova for sharing their data; Robert Zatorre, Emily Coffey and Christine Lefebvre for guidance and suggestions regarding the participant questionnaires, Sylvain Milot for technical support and Christian O'Reilly for the OMEGA acronym.

## References

Baillet, S., Mosher, J., Leahy, R., 2001. Electromagnetic brain mapping. IEEE Signal Process. Mag. 18 (6), 14–30.

Coffey, E.B.J., Herholz, S.C., Scala, S., Zatorre, R.J., 2011. Montreal Music History Questionnaire: a tool for the assessment of music-related experience. Presented at the The Neurosciences and Music IV: Learning and Memory Conference, Edinburgh, UK.

Collins, F.S., Morgan, M., Patrinos, A., 2003. The Human Genome Project: lessons from large-scale biology. Science 300, 286–290. http://dx.doi.org/10.1126/science.1084564.

Das, S., Zijdenbos, A.P., Harlap, J., Vins, D., Evans, A.C., 2012. LORIS: a web-based data management system for multi-center studies. Front. Neuroinform. 5, 37. http://dx.doi.org/10.3389/fninf.2011.00037 (Available at: www.loris.ca).

Das, S., Glatard, T., MacIntyre, L.C., Madjar, C., Rogers, C., Rousseau, M.-E., Rioux, P., MacFarlane, D., Mohaddes, Z., Makowski, C., Niso, G., Moreau, J.T., Evans, A.C., 2016. The MNI data-sharing and processing ecosystem. NeuroImage 124, 1185–1192 (in this issue).

Fernández, A., Zuluaga, P., Abásolo, D., Gómez, C., Serra, A., Méndez, M.A., Hornero, R., 2012. Brain oscillatory complexity across the life span. Clin. Neurophysiol. 123, 2154–2162. http://dx.doi.org/10.1016/j.clinph.2012.04.025.

Gross, J., Baillet, S., Barnes, G.R., Henson, R.N., Hillebrand, A., Jensen, O., Jerbi, K., Litvak, V., Maess, B., Oostenveld, R., Parkkonen, L., Taylor, J.R., van Wassenhove, V., Wibral, M., Schoffelen, J.-M., 2013. Good practice for conducting and reporting MEG research. NeuroImage 65, 349–363. http://dx.doi.org/10.1016/j.neuroimage.2012.10.001.

Huang, M.-X., Nichols, S., Baker, D.G., Robb, A., Angeles, A., Yurgil, K.A., Drake, A., Levy, M., Song, T., McLay, R., Theilmann, R.J., Diwakar, M., Risbrough, V.B., Ji, Z., Huang, C.W., Chang, D.G., Harrington, D.L., Muzzatti, L., Canive, J.M., Christopher Edgar, J., Chen, Y.-H., Lee, R.R., 2014. Single-subject-based whole-brain MEG slow-wave imaging approach for detecting abnormality in patients with mild traumatic brain injury. NeuroImage Clin. 5, 109–119. http://dx.doi.org/10.1016/j.nicl.2014.06.004.

Larson-Prior, L.J., Oostenveld, R., Della Penna, S., Michalareas, G., Prior, F., Babajani-Feremi, A., Schoffelen, J.-M., Marzetti, L., de Pasquale, F., Di Pompeo, F., Stout, J., Woolrich, M., Luo, Q., Bucholz, R., Fries, P., Pizzella, V., Romani, G.L., Corbetta, M., Snyder, A.Z., WU-

Minn HCP Consortium, 2013. Adding dynamics to the Human Connectome Project with MEG. NeuroImage 80, 190–201. http://dx.doi.org/10.1016/j.neuroimage.2013.05.056.

Moreau, J., 2014. BrainDir uploader. Available at. https://github.com/jeremymoreau/braindir_uploader.

Niso, G., Bruña, R., Pereda, E., Gutiérrez, R., Bajo, R., Maestú, F., del-Pozo, F., 2013. HERMES: towards an integrated toolbox to characterize functional and effective brain connectivity. Neuroinformatics 11 (4), 405–434. http://dx.doi.org/10.1007/s12021-013-9186-1 (Available at: http://hermes.ctb.upm.es/).

Poline, J.-B., Breeze, J.L., Ghosh, S., Gorgolewski, K., Halchenko, Y.O., Hanke, M., Haselgrove, C., Helmer, K.G., Keator, D.B., Marcus, D.S., Poldrack, R.A., Schwartz, Y., Ashburner, J., Kennedy, D.N., 2012. Data sharing in neuroimaging research. Front. Neuroinform. 6, 9. http://dx.doi.org/10.3389/fninf.2012.00009.

Stefan, H., Hummel, C., Scheler, G., Genow, A., Druschky, K., Tilz, C., Kaltenhäuser, M., Hopfengärtner, R., Buchfelder, M., Romstöck, J., 2003. Magnetic brain source imaging of focal epileptic activity: a synopsis of 455 cases. Brain 126, 2396–2405. http://dx.doi.org/10.1093/brain/awg239.

Tadel, F., Baillet, S., Mosher, J.C., Pantazis, D., Leahy, R.M., 2011. Brainstorm: a user-friendly application for MEG/EEG analysis. Comput. Intell. Neurosci. 2011, 879716. http://dx.doi.org/10.1155/2011/879716 (Available at: http://neuroimage.usc.edu/brainstorm/).