0622

Frequency Drift in MR Spectroscopy: An 87-scanner 3T Phantom Study

Steve C.N. Hui[1,2], Mark Mikkelsen[1,2], Helge J. Zöllner[1,2], Vishwadeep Ahluwalia[3], Sarael Alcauter[4], Laima Baltusis[5], Deborah A. Barany[6], Laura R. Barlow[7], Robert Becker[8], Jeffrey I. Berman[9], Adam Berrington[10], Pallab K. Bhattacharyya[11], Jakob Udby Blicher[12], Wolfgang Bogner[13], Mark S. Brown[14], Vince D. Calhoun[15], Ryan Castillo[16], Kim M. Cecil[17], Yeo Bi Choi[18], Winnie C.W. Chu[19], William T. Clarke[20], Alexander R. Craven[21], Koen Cuypers[22], Michael Dacko[23], Camilo de la Fuente-Sandoval[24], Patricia Desmond[25], Aleksandra Domagalik[26], Julien Dumont[27], Niall W. Duncan[28], Ulrike Dydak[29], Katherine Dyke[30], David A. Edmondson[17], Gabriele Ende[8], Lars Ersland[31], C. John Evans[32], Alan S. R. Fermin[33], Antonio Ferretti[34], Ariane Fillmer[35], Tao Gong[36], Ian Greenhouse[37], James T. Grist[38], Meng Gu[39], Ashley D. Harris[40], Katarzyna Hat[41], Stefanie Heba[42], Eva Heckova[13], John P. Hegarty II[43], Kirstin-Friederike Heise[44], Aaron Jacobson[45], Jacobus F.A. Jansen[46], Christopher W. Jenkins[47], Stephen J. Johnston[48], Christoph Juchem[49], Alayar Kangarlu[50], Adam B. Kerr[5], Karl Landheer[51], Thomas Lange[52], Phil Lee[53], Swati Rane Levendovszky[54], Catherine Limperopoulos[55], Feng Liu[56], William Lloyd[57], David J. Lythgoe[58], Maro G. Machizawa[59], Erin L. MacMillan[7], Richard J. Maddock[60], Andrei V. Manzhurtsev[61], María L. Martinez-Gudino[62], Jack J. Miller[63], Heline Mirzakhanian[64], Paul G. Mullins[65], Jamie Near[66], Wibeke Nordhøy[67], Georg Oeltzschner[1,2], Raul Osorio[62], Maria C.G. Otaduy[68], Erick H. Pasaye[4], Ronald Peeters[69], Scott J. Peltier[70], Ulrich Pilatus[71], Nenad Polomac[71], Eric C. Porges[72], Subechhya Pradhan[55], James Joseph Prisciandaro[73], Nick Puts[74], Caroline D. Rae[75], Francisco Reyes-Madrigal[76], Timothy P.L. Roberts[9], Caroline E. Robertson[77], Muhammad G. Saleh[78], Jens T. Rosenberg[79], Diana-Georgiana Rotaru[58], O'Gorman Tuura L. Ruth[80], Kristian Sandberg[12], Ryan Sangill[81], Keith Schembri[82], Anouk Schrantee[83], Natalia A. Semenova[84], Debra Singel[85], Rouslan Sitnikov[86], Jolinda Smith[87], Yulu Song[36], Craig Stark[88], Diederick Stoffers[89], Stephan P. Swinnen[44], Costin Tanase[60], Sofie Tapper[1,2], Martin Tegenthoff[42], Thomas Thiel[90], Marc Thioux[91], Peter Truong[92], Pim van Dijk[91], Nolan Vella[82], Rishma Vidyasagar[93], Andrej Vovk[94], Guangbin Wang[36], Lars T. Westle[67], Timothy K. Wilbur[54], William R. Willoughby[95], Martin Wilson[96], Hans-Jörg Wittsack[97], Adam J. Woods[98], Yen-Chien Wu[99], Junqian Xu[100], Maria Yanez Lopez[101], David K.W. Yeung[19], Qun Zhao[102], Xiaopeng Zhou[29], Gasper Zupan[94], and Richard A.E. Edden[1,2]

[1]Russell H. Morgan Department of Radiology and Radiological Science, The Johns Hopkins University School of Medicine, Baltimore, MD, United States, [2]F.M. Kirby Research Center for Functional Brain Imaging, Kennedy Krieger Institute, Baltimore, MD, United States, [3]GSU/GT Center for Advanced Brain Imaging, Georgia Institute of Technology, Atlanta, GA, United States, [4]Instituto de Neurobiología, Universidad Nacional Autónoma de México, Queretaro, Mexico, [5]Center for Cognitive and Neurobiological Imaging, Stanford University, Stanford, CA, United States, [6]Kinesiology, University of Georgia, Athens, GA, United States, [7]Department of Radiology, The University of British Columbia, Vancouver, BC, Canada, [8]Center for Innovative Psychiatry and Psychotherpay Research, Department Neuroimaging, Central Institute of Mental Health, Medical Faculty Mannheim, Heidelberg University, Mannheim, Germany, [9]Department of Radiology, Children's Hospital of Philadelphia, Philadelphia, PA, United States, [10]Sir Peter Mansfield Imaging Centre, School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom, [11]Imaging Institute, The Cleveland Clinic, Cleveland, OH, United States, [12]Center of Functionally Integrative Neuroscience, Aarhus University, Aarhus, Denmark, [13]Department of Biomedical Imaging and Image-guided Therapy, High-Field MR Center, Medical University of Vienna, Vienna, Austria, [14]Department of Radiology, University of Colorado Anschutz Medical Campus, Aurora, CO, United States, [15]Tri-Institutional Center for Translational Research in Neuroimaging and Data Science(TReNDS), Georgia State University, Georgia Institute of Technology, and Emory University, Atlanta, GA, United States, [16]Neuroscience Research AustraliaNeuRA Imaging, Randwick, Australia, [17]Department of Radiology, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, United States, [18]Psychological and Brain Sciences, Dartmouth College, Hanover, NH, United States, [19]Department of Imaging & Interventional Radiology, The Chinese University of Hong Kong, Hong Kong, Hong Kong, [20]Wellcome Centre for Integrative Neuroimaging, NDCN, University of Oxford, Oxford, United Kingdom, [21]Department of Biological and Medical Psychology, University of Bergen, Haukeland University Hospital, Bergen, Norway, [22]REVAL Rehabilitation Research Institute (REVAL), Hasselt University, Diepenbeek, Belgium, [23]Department of Radiology, Medical Physics, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany, [24]Laboratory of Experimental Psychiatry & Neuropsychiatry Department, Instituto Nacional de Neurología y Neurocirugía, Mexico City, Mexico, [25]Department of Radiology, University of Melbourne/ Royal Melbourne Hospital, Melbourne, Australia, [26]Malopolska Centre of Biotechnology, Jagiellonian University, Krakow, Poland, [27]Clinical Imaging Core Facility, CI2C Lille, Lille, France, [28]Graduate Institute of Mind, Brain and Consciousness, Taipei Medical University, Taipei, Taiwan, [29]School of Health Sciences, Purdue University, West Lafayette, IN, United States, [30]School of Psychology, University of Nottingham, Nottingham, United Kingdom, [31]Department of Clinical Engineering, University of Bergen, Haukeland University Hospital, Bergen, Norway, [32]CUBRIC, Cardiff University, Cardiff, United Kingdom, [33]Center for Brain, Mind and Kansei Sciences Research, Hiroshima University, Hiroshima, Japan, [34]Neuroscience, Imaging and Clinical Sciences, University "G. d'Annunzio" of Chieti-Pescara, Chieti, Italy, [35]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig und Berlin, Germany, [36]Department of Imaging and Nuclear Medicine, Shandong Medical Imaging Research Institute, Shandong University, Jinan, China, [37]Human Physiology, University of Oregon, Eugene, OR, United States, [38]Physiology, Anatomy, and Genetics/ Oxford Centre for Magnetic Resonance, The University of Oxford / Department of Radiology, The Churchill Hospital, The University of Oxford, Oxford, United Kingdom, [39]Department of Radiology, Stanford University, Stanford, CA, United States, [40]Department of Radiology, University of Calgary, Calgary, AB, Canada, [41]Institute of Psychology, Jagiellonian University, Krakow, Poland, [42]Department of Neurology, BG University Hospital Bergmannsheil, Bochum, Germany, [43]Psychiary & Behavioral Sciences, Stanford University, Stanford, CA, United States, [44]Department of Movement Sciences, KU Leuven, Leuven, Belgium, [45]Department of Radiology, University of California San Diego, San Diego, CA, United States, [46]Department of Radiology and Nuclear Medicine, Maastricht University Medical Center, Maastricht, Netherlands, [47]CUBRIC, Cardiff university, Cardiff, United Kingdom, [48]Psychology Dept. / Clinical Imaging Facility, Swansea University, Swansea, United Kingdom, [49]Biomedical Engineering and Radiology, Columbia University, New York City, NY, United States, [50]Psychiatry, Columbia University Irving Medical Center/New York State Psychiatric Institute, New York City, NY, United States, [51]Biomedical Engineering, Columbia University, New York City, NY, United States, [52]Department of Radiology, Medical Physics, University of Freiburg, Freiburg, Germany, [53]Department of Radiology, University of Kansas Medical Center, Kansas, KS, United States, [54]Department of Radiology, University of Washington, Seattle, WA, United States, [55]Developing Brain Institute, Diagnostic Imaging and Radiology, Children's National Hospital, Washington, DC, United States, [56]Department of Psychiatry, Columbia University Irving Medical Center/New York State Psychiatric Institute, New York, NY, United States, [57]Division of Informatics, Imaging & Data Sciences, University of Manchester, Manchester, United Kingdom, [58]Department of Neuroimaging, King's College London, London, United Kingdom, [59]Center for Brain, Mind and KANSEI Sciences Research, Hiroshima University, Hiroshima, Japan, [60]Psychiatry and Behavioral Sciences, University of California Davis, Imaging Research Center, Davis, CA, United States, [61]Department of Radiology, Clinical and Research Institute of Emergency Pediatric Surgery and Trauma, Moscow, Russian Federation, [62]Imágenes Cerebrales, Instituto Nacional de Psiquiatría Ramón de la Fuente, Mexico City, Mexico, [63]Department of Physics, University of Oxford, Oxford, United Kingdom, [64]Department of Psychiatry, University of California San Diego, San Diego, CA, United States, [65]Department of Psychology, Bangor University, Bangor, United Kingdom, [66]Douglas Mental Health University Institute and Department of Psychiatry, McGill University, Montreal, QC, Canada, [67]Department of Diagnostic Physics, Division of Radiology and Nuclear Medicine, Oslo University Hospital, Oslo, Norway, [68]LIM44, Instituto e Departamento de Radiologia, Faculdade de Medicina, Universidade de Sao Paulo, Sao Paulo, Brazil, [69]Department of Imaging & Pathology, Department of Radiology, University Hospitals Leuven, KU Leuven, Leuven, Belgium, [70]Functional MRI Laboratory, University of Michigan, Ann Arbor, MI, United States, [71]Institute of Neuroradiology, Goethe-University Frankfurt, Frankfurt, Germany, [72]Center for Cognitive Aging and Memory, McKnight Brain Institute, Department of Clinical and Health Psychology, College of Public Health and Health Professions, University of Florida, Gainesville, FL, United States, [73]Psychiatry and Behavioral Sciences, Medical University of South Carolina, Charleston, SC, United States, [74]Forensic & Neurodevelopmental Sciences, King's College London, London, United Kingdom, [75]NeuRA Imaging, Neuroscience Research Australia, Randwick, Australia, [76]Laboratory of Experimental Psychiatry, Instituto Nacional de Neurología y Neurocirugía, Mexico City, Mexico, [77]Department of Psychological and Brain Sciences, Dartmouth College, Hanover, NH, United States, [78]Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, United States, [79]McKnight Brain Institute, AMRIS, University of Florida, Gainesville, FL, United States, [80]Center for MR Research, University Children's Hospital, Zurich, Switzerland, [81]Center of Functionally Integrative Neuroscience, Aarhus University Hospital, Aarhus, Denmark, [82]Medical Physics, Mater Dei Hospital, Imsida, Malta, [83]Department of Radiology and Nuclear Medicine, Amsterdam University Medical Center, University of Amsterdam, Amsterdam, Netherlands, [84]504, Emanuel Institute of Biochemical Physics of the Russian Academy of Sciences, Moscow, Russian Federation, [85]Psychiatry, University of Colorado Anschutz Medical Campus, Aurora, CO, United States, [86]Clinical Neuroscience, MRI Centre, Karolinska Institutet, Clinical Neuroscience, MRI Centre, Sweden, [87]Lewis Center for Neuroimaging, University of Oregon, Eugene, OR, United States, [88]Department of Neurobiology and Behavior, Facility for Imaging and Brain Research (FIBRE) & Campus Center for Neuroimaging (CCNI), University of California, Irvine, Irvine, CA, United States, [89]Spinoza Centre for Neuroimaging, Royal Netherlands Academy of Arts and Sciences, Amsterdam, Netherlands, [90]Institute of Clinical Neuroscience and Medical Psychology, University Dusseldorf, Medical Faculty, Düsseldorf, Germany, [91]Otorhinolaryngology, Head and Neck Surgery, University of Groningen, University Medical Center Groningen, Groningen, Netherlands, [92]Brain Health Imaging Centre, Centre for Addiction and Mental Health, Toronto, ON, Canada, [93]Melbourne Dementia Research Centre, Florey Institute of Neurosciences and Mental Health, Melbourne, Australia, [94]Faculty of Medicine, University of Ljubljana, Ljubljana, Slovenia, [95]Department of Radiology, University of Alabama at Birmingham, Birmingham, AL, United States, [96]Centre for Human Brain Health, University of Birmingham, Birmingham, United Kingdom, [97]Department of Diagnostic and Interventional Radiology, University Dusseldorf, Medical Faculty, Düsseldorf, Germany, [98]Center for Cognitive Aging and Memory, McKnight Brain Institute, Department of Clinical and Health Psychology, College of Public Health and Health Professions. Department of Neuroscience, College of Medicine, University of Florida, Gainesville, FL, United States, [99]Department of Radiology, TMU-Shuang Ho Hospital, New Taipei City, Taiwan, [100]Department of Radiology and Psychiatry, Baylor College of Medicine, Houston, TX, United States, [101]Perinatal Imaging & Health, King's College London, London, United Kingdom, [102]Bioimaging Research Center, University of Georgia, Athens, GA, United States

Synopsis

This project aimed to examine the relationship between gradient-induced heating and field drift on a large sample of MRI scanners. A standardized phantom protocol was established, and spectroscopy was performed before and after running 10 minutes of echo-planar imaging (EPI). MRS data were acquired from 87 scanners. The frequency drift trace was extracted by modeling the water signal in each transient. Drift rates of up to 1.3 Hz/minute were seen before EPI, and 4 Hz/minute after. This dataset will allow sites to benchmark scanner drift, for consideration in planning research protocol order and examine the need for real-time field-frequency locking.

Introduction

Heating of the gradient coils and thermal dissipation to the passive shims is a common cause of instability in the B_0 field, especially when echo-planar imaging (EPI) sequences are used (1-3). B_0 field drift changes the resonance frequency of spins, resulting in line broadening, decreased SNR and changes in editing efficiency for edited MRS experiments which rely on accurately placing frequency-selective pulses. To examine the extent and impact of gradient-induced frequency drift, a standardized protocol was distributed to sites with scanners from three vendors. By collecting data from a large number of sites, we aim to establish 'typical' levels of drift for benchmarking purposes, and to assess whether there is a widespread need for real-time field-frequency locking (2).

Methods

Phantom water signals were acquired with PRESS localization before and after a BOLD-weighted fMRI sequence. Standardized protocols were generated for GE, Philips and Siemens scanners consisting of: minimal preparatory imaging; pre-fMRI PRESS (TR/TE 5000/35 ms; 64 transients with data stored separately; no water suppression; voxel size 2 × 2 × 2 cm^3, duration = 5:20 min); EPI BOLD sequence based on the ADNI-3 (4) protocol (TR/TE 3000/30 ms; 197 dynamics of one average; EPI factor 31, scan duration 10 min); and a long post-fMRI PRESS sequence (360 transients; other parameters same as pre-fMRI PRESS). Sites were instructed to use a water-dominant phantom of spherical or cylindrical shape. Phased-array head or head-and-neck coils with between 8 and 64 channels were used. Scanning was performed at least 6 hours after the previous scan to avoid any drift confounds due to heating effects. Phantoms were acclimatized in the scan room for the same period, and positioned at scanner isocenter. Spectral analysis was performed using MATLAB (R2020b, MathWorks, Natick, USA), including eddy-current correction, zero-filling and Fourier transformation. Frequency-domain pre- and post-fMRI PRESS spectra were modeled using a Lorentzian-Gaussian (Voigt) lineshape model to extract the water peak center frequency from each individual transient. In order to compare frequency drift before and after EPI, the mean absolute frequency offset of the first 64 dynamics was calculated, and paired t-test was performed between pre- and post-fMRI PRESS. To visualize the effect of the observed frequency drifts on a typical 5-minute in vivo protocol, a simulated in vivo spectrum was generated using FID-A (5), including 18 major metabolites (TE = 35 ms; 2048 samples; 2 kHz spectral width, 2 Hz linewidth). The simulated spectrum was convolved with the frequency trace from the first 64 TRs of the phantom recording and spectra plotted. Fifty-eight sites repeated the acquisition protocol on a different day to allow investigation of the reproducibility of frequency drift traces. Pearson and intraclass correlation coefficients (ICC) were calculated between the two runs using the 'psych' R package (6). ICC calculation was based on a two-way mixed-effects model with average measures of absolute agreement.

Results

Data were received from 71 sites and 87 scanners (GE = 20, Philips = 28, Siemens = 39; 58 scanners submitted repeat data). Figure 1 shows the individual spectra for the highest-drifting scanner, before and after fMRI, with the frequency drift traces. Figure 2 shows the frequency drift traces overlaid for all 87 scanners. Scanners drifted by up to 7 Hz within 5 minutes before fMRI and by up to 26 Hz within 30 minutes after fMRI. Figure 3 shows a box plot of the absolute average frequency offset of each scanner (7). The mean absolute frequency offset across 64 transients (~5 min) was 0.78 ± 0.87 Hz (median = 0.4 Hz) and 1.33 ± 1.42 Hz (median = 0.8 Hz) respectively before and after fMRI. T-tests indicated drifting was significantly increased ($p < 0.05$) after fMRI, as expected. Simulated spectra that have been convolved with 64-transient water traces (the highest and lowest drift case for each vendor pre- and post-fMRI) are shown in Figure 4. The intensity of the NAA singlet is reduced by up to 26%, 44 % and 18% for GE, Philips and Siemens respectively, after fMRI. Since drift does not impact the noise, these peak signal losses represent predicted losses of SNR. Drift behavior was well correlated and reproducible. ICCs were 0.85 and 0.95 for pre- and post-fMRI PRESS repeated datasets, respectively. Pearson correlation coefficients (0.74 and 0.90) also showed good correlation between repeated datasets.

Discussion

Frequency drift data are presented for eighty-seven 3T MRI scanners. Median levels of drift were relatively low (5-minute average under 1 Hz), but the most extreme case suffered from higher levels of drift (up to 3.5 Hz before and 7.2 Hz after fMRI). These levels of drift lead to a measurable loss in SNR for short-TE MRS, as well as changes in editing efficiency and subtraction artefacts in edited MRS. Although the difference between pre- and post-fMRI was significant, it was lower than expected and there appears to be substantial drift associated with running scans 'from cold', as indicated by the pre-fMRI traces after only minimal preparatory imaging. Correlation analysis indicated that the drift was highly repeatable between sessions, so one might expect drift associated with previous scans within a protocol to be consistent.

Acknowledgements

This work was supported by NIH grants R01 EB016089, R01 EB023963, R21 AG060245, K99 EB028828 and K99 AG062230.

References

1. Foerster BU, Tomasi D, Caparelli EC. Magnetic field shift due to mechanical vibration in functional magnetic resonance imaging. Magn Reson Med 2005;54(5):1261-1267.
2. Henry PG, van de Moortele PF, Giacomini E, Nauerth A, Bloch G. Field-frequency locked in vivo proton MRS on a whole-body spectrometer. Magn Reson Med 1999;42(4):636-642.
3. Rowland BC, Liao H, Adan F, Mariano L, Irvine J, Lin AP. Correcting for Frequency Drift in Clinical Brain MR Spectroscopy. J Neuroimaging 2017;27(1):23-28.
4. Weiner MW, Veitch DP, Aisen PS, et al. The Alzheimer's Disease Neuroimaging Initiative 3: Continued innovation for clinical trial improvement. Alzheimers Dement 2017;13(5):561-571.
5. Simpson R, Devenyi GA, Jezzard P, Hennessy TJ, Near J. Advanced processing and simulation of MRS data using the FID appliance (FID-A)-An open source, MATLAB-based toolkit. Magn Reson Med 2017;77(1):23-33.
6. R Core Team R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. 2020.
7. Zöllner HJ, Považan M, Hui SCN, Tapper S, Edden RAE, Oeltzschner G. Comparison of different linear-combination modelling algorithms for short-TE proton spectra. bioRxiv 2020:2020.2006.2005.136796.

Figures

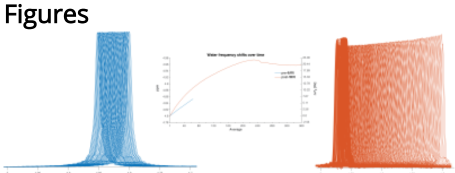

Figure 1. Individual transients of pre- and post-fMRI PRESS (plotted in blue and red, respectively) from the highest-drifting scanner. The frequency offset derived from modeling the water signals is plotted (middle). 360 averages correspond to 30 minutes total scan duration.

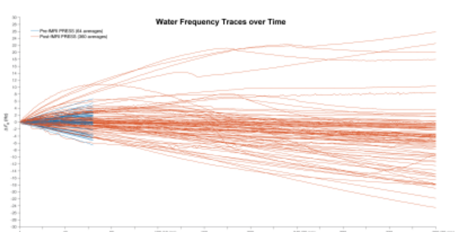

Figure 2. Water offset traces of all 87 scanners. Pre- and post-fMRI traces are plotted in blue and red, respectively. 360 averages correspond to 30 minutes total scan duration.

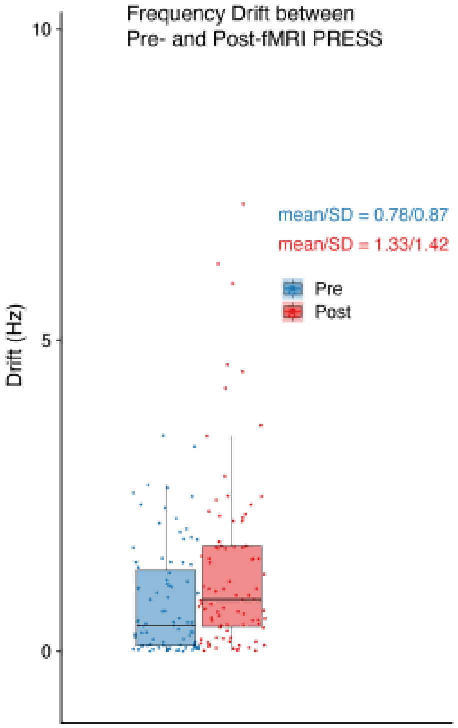

Figure 3. Box plot for the mean absolute frequency offset for pre- and post-fMRI PRESS data on each scanner.

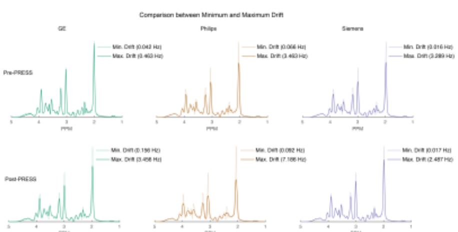

Figure 4. Comparison of simulated spectra with frequency drift applied between minimum and maximum drift for pre- and post-fMRI PRESS data. The minimum-drift case for each vendor (50% opacity) is overlaid with the maximum-drift case (opaque).

Proc. Intl. Soc. Mag. Reson. Med. 29 (2021)
0622