LIST OF NEUROSCIENCE TECHNIQUES TO STUDY BRAIN ACTIVITY IN VIVO

Following the LLM Output, it became necessary to screen for possible unfeasible techniques, duplicates, or even those that don't necessarily meet the *In Vivo* criteria.

A justification is provided for each exclusion. The main rational is that with that technique it is feasible to see a dynamic change at least in a time resolution of <1h

Later, another step will be necessary in order to merge the second step output with this list (in a separate file for proper documentation).

O = Out / Excluded
I = In / Included
U = Undecided

A. Magnetic / MRI-Related (Non-Invasive)

1. Functional Connectivity MRI (fcMRI) [**I**]
Basically the same as general fMRI, just changing the analysis methods for the same sequences;

2. Resting-State fMRI (rs-fMRI) [**O**]
Basically the same as general fMRI, just changing the analysis methods for the same sequences; ***Will mark it as a subset for other BOLD like***

3. Magnetic Particle Imaging (MPI) [**I**]
There's evidence of it as a proper new functional tool
https://doi.org/10.18416%2FIJMPI.2020.2009009
https://en.wikipedia.org/wiki/Magnetic_particle_imaging

4. Susceptibility-Weighted Imaging (SWI) [**I**]
Requires distinct methods from the typical bold, so a technique in its own right.

5. Quantitative Susceptibility Mapping (QSM) [**I**]
There are hints that it can be used in a functional manner
(https://doi.org/10.1016/j.neuroimage.2021.117924)

6. Functional MRS (fMRS) [**I**]
Review arguing on its feasibility https://doi.org/10.1016/j.neuroimage.2023.120194

7. Magnetic Resonance Elastography (MRE) [**I**]
Although very incipient, there are some attempts on doing it in a ''functional" manner.
https://archive.ismrm.org/2014/0871.html
https://doi.org/10.3389/fbioe.2021.666456

8. Chemical Exchange Saturation Transfer (CEST) fMRI [**I**]
There exists the possibility to perform functional analysis with it, and there are some studies showing its feasibility.
https://doi.org/10.1038/s41598-019-40986-9
https://anr.fr/Project-ANR-19-CE17-0008
https://onlinelibrary.wiley.com/doi/abs/10.1002/jmri.27850

9. Microvascular Volumetric Pulsatility Mapping [**U**]
It is not, for the moment, used to dynamically probe brain activity, but it could be
https://doi.org/10.1038/s44161-025-00722-1

10.Neurite Orientation Dispersion and Density Imaging (NODDI) [**O**]
More structural than activity-oriented. It is a great tool to study long term structural changes, but outside our scope.
https://doi.org/10.1111/jon.13125

11.Neuromelanin-Sensitive MRI [**O**]
Structural / with functionality flavor, but no dynamic assessment in shot time scales
https://doi.org/10.1093/brain/awad300

12.Free-Water Diffusion Imaging [**O**]
All current studies are structural in nature, no dynamics
https://doi.org/10.3233/JAD-231416
https://doi.org/10.1162/imag_a_00252

13. Optically Pumped Magnetometer MEG (OPM-MEG) [**I**]
Room-temperature, scalp-proximate optically pumped magnetometer arrays for high-sensitivity, flexible MEG recordings in naturalistic and mobile settings.

14.Hyperpolarized 13C Metabolic MRI [**I**]
Real-time metabolic flux imaging using hyperpolarized 13C tracers to measure rapid changes in brain energy metabolism linked to neural activity.
https://doi.org/10.1073/pnas.1613345114
https://doi.org/10.1016/j.neuroimage.2022.119284 (although static, could apply acquisitions in time as the first link)

15.Magnetic Resonance Fingerprinting (MRF) [**I**]
Rapid, quantitative multiparametric tissue mapping for assessing dynamic physiological changes during brain activity
https://doi.org/10.1002/jmri.29812

16.VASO (Cerebral Blood Volume fMRI) [**I**]
Well established technique

17.Q-ball Imaging [**O**]
Structural technique, a "branch" of DTI
https://doi.org/10.1111/cgf.15082
https://doi.org/10.30476/jamsat.2021.48382

18.Continuous Arterial Spin Labeling (CASL) [**I**]
Non-invasive perfusion MRI method using continuous RF inversion of arterial water for quantitative CBF mapping.
https://doi.org/10.3389/fradi.2022.929533

19.Pulsed Arterial Spin Labeling (PASL) [**I**]
ASL variant using short RF pulses to label arterial blood, offering different trade-offs for perfusion imaging.
https://doi.org/10.3389/fradi.2022.929533

20.31P Magnetic Resonance Spectroscopy **[I]**
There is evidence of dynamic assessment
https://doi.org/10.1002/nbm.70043

21.23Na Sodium MRI [**I**]
Few studies showing dynamic feasibility; but they do exist;
https://doi.org/10.1016/j.neuroimage.2018.09.071
https://archive.ismrm.org/2025/2503_bFbEoFQ1W.html

22.Intravoxel Incoherent Motion (IVIM) MRI [**I**]
There has been proof of concept
https://doi.org/10.1371/journal.pone.0117706

B. PET / Radiotracer Advances

20.Fiber-Coupled PET Detectors (minimally invasive) [**O**]
Trying to understand what the LLMs meant by this (Hallucination?). All the literature involved seems to be a dead end or not quite related to it.
https://doi.org/10.1016/j.neuroimage.2019.02.064

21.Neuroimmune PET Ligands (TSPO, CSF1R etc.) [**O**]
For studying microglial/astrocyte activation. But its temporal resolution places it outside our definition. Studies generally make cohorts to perform follow ups.
https://doi.org/10.2967/jnumed.119.229443
https://doi.org/10.1016/S1474-4422(20)30346-X
https://doi.org/10.1186/s12974-019-1604-3

22.Total-Body PET Imaging [**I**]
Enables whole-brain dynamic imaging with unprecedented temporal resolution and sensitivity. Although its temporal resolution is at the limit in relation to our criteria thresholds, it should be kept in mind and thus included.
https://doi.org/10.1259/bjr.20220357
https://doi.org/10.2967/jnumed.119.231845
https://doi.org/10.1007/s00259-022-06057-4

23.Positronium Lifetime Imaging [**O**]
Emerging PET technique providing information about tissue microenvironment, but still within the static domain due to unfeasibility to perform dynamic assessments.

https://iopscience.iop.org/article/10.1088/1361-6560/ad9543
https://doi.org/10.1126/sciadv.adp2840

24. Synaptic Vesicle Glycoprotein 2A (SV2A) PET Imaging [**O**]
Uses tracers like [^{11}C]UCB-J to quantify synaptic density in vivo. But does not have adequate time resolution to perform dynamic assessment of Brain activity. The Binding dynamics are assessed in temporal resolutions of hours, days.
https://doi.org/10.3389/fnins.2022.787404
https://doi.org/10.3389/fnins.2022.864514
https://jamanetwork.com/journals/jamaneurology/fullarticle/2687472

25. Mitochondrial Complex I PET Imaging [**O**]
Employs [^{12}F]BCPP-EF to assess mitochondrial function and energy metabolism related to neural activity. But falls in the same problem as above.
https://doi.org/10.1016/j.bpsc.2025.02.007 (this paper for instance, relies on BOLD for dynamic assessment)

26.CSF1R PET for Neuroinflammation [**O**]
Tracers like [^{11}C]CPPC to image microglial activation during brain processes. Again, lacks temporal resolution to study dynamic changes that fit into our definition.
https://doi.org/10.1016/j.nucmedbio.2022.10.003
https://doi.org/10.1007/s11307-025-01991-9

27.Positron Emission Metabolic Tracing with Short-Lived Isotopes (rapid kinetic PET) [**I**]
High-temporal-resolution PET protocols using short-lived radiotracers and fast kinetic modeling to track sub-minute metabolic changes associated with neural events.
https://doi.org/10.1002/acn3.51546
https://doi.org/10.1007/s00259-023-06542-4

28.μ-opioid Receptor PET ([^{11}C]carfentanil) [**I**]
It's actually possible to perform studies with time dynamics, or at least extrapolated time dynamics. Here there's a 120 time window of study. But it has a very specific study design. Could this approach be expanded to other radiotracers?
https://doi.org/10.1007/s00259-024-06746-2

29.Dopamine D2/D3 Receptor Occupancy PET [**I**]
The temporal dynamics of certain studies fall out of our definition. But as with many of the radioligands, the same approach used in 28 could theoretically be used. The third study points to a more appropriate time frame, thus leading to inclusion.
https://doi.org/10.1038/s41386-023-01622-3
https://doi.org/10.1038/s42003-022-03434-5
https://doi.org/10.1177/0271678X231210128

30.Cerebral Metabolic Rate of Oxygen (CMRO2) PET [**I**]
Quantitative imaging of oxygen metabolism using ^{15}O-labeled tracers. It uses several interesting approaches.
https://doi.org/10.1016/j.neuroimage.2020.117136
https://doi.org/10.2967/jnumed.120.260521

31.Astrocyte-Specific PET Tracers (^{11}C-deuterium-L-deprenyl) [**O**]
Targets monoamine oxidase B in astrocytes for glial activity mapping. But papers fall in the above problem of its temporal dynamics.
https://doi.org/10.2967/jnumed.115.168732
https://doi.org/10.1186/s13024-023-00647-y

32.GABA-A Receptor PET ([^{18}F]flumazenil) [**I**]
Images inhibitory neurotransmission by binding to GABA-A receptors, can be used to study dynamic uptake. Within appropriate time frames. Although the below study would not be strictly fitted into our criteria, nothing stops us from studying stimuli and others within the time PET frame of acquisition.
https://doi.org/10.3390/ph16030417

33.Serotonin Transporter PET ([^{11}C]DASB) [**I**]
Quantifies serotonin transporter density and availability as a proxy for serotonergic neural activity. Study uses the Time-Activity Curves approach.
https://doi.org/10.3390/ijms26010252

34.AMPA Receptor PET ([^{11}C]K-2) [**O**]
Detects glutamatergic synaptic activity through AMPA receptor binding in vivo. But there appears to not be any temporal dynamically available study.
https://doi.org/10.1038/s41598-021-81002-3
https://doi.org/10.1016/j.neures.2021.05.009
https://doi.org/10.1016/j.xcrm.2023.101020

General Observation: *All these PET approaches could theoretically be temporally dynamic if they used the approaches already established for some tracers. Perhaps there's specificities associated with the Kinetics of each that prevent it, but I should make this consideration when discussing these approaches.*

C. Electrophysiology & Implant Technologies

32.Neuropixels Probes (latest gen) [**I**]
Not just "multielectrode"; Neuropixels constitute a distinct class due to ultra-high channel count (1,000+), used in vivo widely.
https://doi.org/10.1016/j.conb.2018.01.009

33.Silicon Probe Laminar Recordings [**O**]
It is hard to argue that these aren't basically the same techniques as Neuropixels;
https://www.sciencedirect.com/science/article/pii/S0924424710005170

34.High-Density "ECoG Grids" (Neuropixels–ECoG hybrids) [**O**]
In essence ECoG, but with higher density. It is a technological advancement within the same technique.

35.EMG-Assisted Brain–Body Coupled Recording [**O**]
It uses existing techniques, by coupling them, but not a novelty in itself. It is a multimodal

approach
https://doi.org/10.1016/j.promfg.2018.06.010

36.Flexible Bioelectronic Neural Interfaces [**I**]
As these encompass several distinct kinds of electrodes, and some of them indeed are novelties (see reference) and couldn't be properly labeled within others, they'll be included
https://doi.org/10.1038/s41563-020-0679-7

37.Transparent Graphene Microelectrode Arrays [**I**]
Allow simultaneous electrical recording and optical imaging/optogenetics. Although it could be argued that these are just a coupling of two distinct techniques, it opens the way for precise integration of distinct information.
https://doi.org/10.1038/s41467-018-04457-5

38.Ultrasonic Neural Dust Motes [**I**]
Wireless, millimeter-scale implants for chronic neural recording. It is a new modality in itself; Although incipient and lacks new publications in the recent years (generally cited in reviews)
https://doi.org/10.1016/j.conb.2017.12.010

39.Optetrode Recordings [**I**]
If 37 is included, so must be this one. It may be interesting to nest these hybrid technologies for later reporting
https://doi.org/10.1038/nn.2992

40.CMOS-Integrated Neural Probes [**I**]
On-chip amplified high-density probes for low-noise in vivo recordings. But could be seen as specific designs within the Neural Probes family. Should be put in this context then
https://doi.org/10.1016/j.snr.2024.100206
https://doi.org/10.1126/sciadv.adf9524

41.Sharp Electrode Intracellular Recordings [**I**]
Classical method in electrophysiology
https://doi.org/10.1016/S0165-0270(03)00126-2

42.Wireless High-Density Neural Probes (wireless Neuropixels variants) [**O**]
It is neuropixels, but wireless; Again, an important technical advance, but that does not change the basic logic beneath the technique.

43.Autonomous Robotic In Vivo Patch-Clamp (AutoPatch / Robopatcher) [**O**]
Automated robotics-enabled intracellular patch-clamp in awake or anesthetized, but still Patch-Clamp. A technical advancement but with the same underlying mechanism.
https://doi.org/10.1152/jn.00738.2018

44. Graphene Field-Effect Transistor Neurochemical Sensors (gFETs) [**I**]
Implantable gFET biosensors for direct, high-sensitivity, real-time detection of neurotransmitters and neuromodulators in vivo with electrical readout. ***Note:*** *But a subtechnique within microdialysis, like HPLC, Capillary Electrophoresis and Mass Spectrometry.*

https://doi.org/10.3390/app142210109
https://doi.org/10.1039/C4AN02027H
https://doi.org/10.1021/acs.nanolett.2c00289 (shows in vivo application)

45.Tetrode Recordings [**I**]
Classical method using four-wire bundles for extracellular recording with improved single-unit isolation.
https://doi.org/10.1016/S0165-0270(02)00092-4

46.Juxtacellular Recording and Labeling [**I**]
Technique for extracellular recording followed by intracellular labeling of recorded neurons.
https://doi.org/10.1016/j.jneumeth.2006.02.004
https://doi.org/10.1038/nprot.2014.161

47.Carbon Fiber Microelectrodes [**I**]
Miniaturized electrodes for electrochemical detection of neurotransmitters with fast-scan cyclic voltammetry.
https://doi.org/10.1523/JNEUROSCI.14-01-00442.1994
https://doi.org/10.1039/C9AN01925A

48.Floating Microelectrode Arrays [**I**]
Untethered microelectrodes that move with brain tissue for stable chronic recordings.
BUT should enter as subtechniques under the microelectrode array "umbrella"
https://doi.org/10.1016/j.jneumeth.2006.09.005

49.Utah Array Recordings [**I**]
High-density silicon-based electrode arrays for chronic cortical extracellular recordings in primates and humans.
BUT should enter as subtechniques under the microelectrode array "umbrella"
https://doi.org/10.1016/S0013-4694(96)95176-0

50.Michigan Probe Recordings [**I**]

Flexible silicon shank probes for multi-site extracellular neural activity mapping in deep brain structures.
BUT should enter as subtechniques under the microelectrode array "umbrella"
https://doi.org/10.1109/10.7273 (one of the first proof of concepts)
https://doi.org/10.1016/j.heares.2008.01.010 (2008 review)

51.Stereotrode Recordings [**I**]
Two-wire electrode bundles for improved spatial resolution in extracellular unit isolation, historical precursor to tetrodes.
Although historic, it must be nested with tetrodes somehow, and within a hierarchical structure encompassing all these electrode categories
https://doi.org/10.1016/0165-0270(83)90097-3
https://doi.org/10.1016/j.jneumeth.2013.11.013

D. Optical / Imaging-Based Techniques

49. Light-Sheet Fluorescence Microscopy (LSFM) In Vivo [**I**]
Now used in small transparent animals (zebrafish, larval models). Technically in vivo and provides whole-brain fast activity imaging.
https://doi.org/10.1038/nmeth.2434
https://doi.org/10.1016/j.jneumeth.2018.07.011
https://doi.org/10.1016/j.conb.2018.03.007
https://doi.org/10.1146/annurev-neuro-070918-050357

50.Swept Confocally-Aligned Planar Excitation (SCAPE) Microscopy [**I**]
High-speed volumetric neural imaging in freely moving animals.
https://doi.org/10.1038/nphoton.2014.323
https://doi.org/10.1038/s41587-020-0628-7

51. Structured-Light 3D Imaging of Cortical Hemodynamics [**I**]
Used to map neural activity via intrinsic signals & hemodynamic changes. Uses Optical Intrinsic Signal {merge both?}
https://doi.org/10.1117/1.NPh.4.2.021102
(alternative link https://pmc.ncbi.nlm.nih.gov/articles/PMC5391480/)

52. Mesoscopic Calcium Imaging (NOT miniscope) [**I**]
Widefield mesoscopic Ca^{2+} imaging in vivo (distinct from fiber photometry).
https://doi.org/10.3389/fnins.2023.1210199
https://doi.org/10.1371/journal.pone.0185759

53. Adaptive Optics for In Vivo Neural Imaging [**I**]
Corrects deep-tissue optical distortion; It is a separate technique in the sense that it allows for better use of the former technologies; but still is reliant on them. Could be considered a technical advancement in the preexisting techniques (two / three photos imaging). Note: After reconsidering, I included it as a new, to be consistent with #15.
https://doi.org/10.3389/fnins.2022.880859
https://doi.org/10.3389/fnins.2023.1188614

54. Oblique Plane Microscopy (OPM) [**I**]
High-resolution, high-speed volumetric imaging for large-scale neural activity monitoring.
https://doi.org/10.1038/s41467-023-43741-x

55. Multifocal/Multibeam Two-Photon Microscopy [**I**]
Simultaneous imaging of multiple planes for 3D functional imaging. But does it allow for In Vivo imaging? Third link shows evidence.
https://doi.org/10.1364/BOE.9.003678
https://doi.org/10.3389/fncel.2019.00039
https://doi.org/10.1364/BOE.514826 (the one that shows feasibility)

56. Line-Scanning Temporal Focusing Microscopy (and also Multiline mosTF) [**I**]
High-speed volumetric imaging with reduced out-of-focus excitation. Although still not many publications focusing on the temporal dynamics of it, it is one of the technique goals.
https://doi.org/10.1038/s41598-024-57208-6
https://doi.org/10.1364/BOE.9.005654

57. Light Field Microscopy [**I**]
Captures volumetric data in a single exposure for fast 3D neural activity imaging.
https://doi.org/10.1016/j.jneumeth.2021.109083

58.Kilohertz Two-Photon Fluorescence Microscopy [**O**]
Ultrafast scanning rates for capturing rapid neuronal dynamics in vivo. But it is in the end Two-Photon Fluorescence, despite its temporal improvement. It should be mentioned when dealing with resolutions themselves.
https://doi.org/10.1364/OPTICA.487272 (important for temporal resolution of the technique)

59. Nanosheet Incorporated into light-curable REsin (NIRE) Cranial Window Method [**O**]
Uses nanosheet-resin windows for large-scale, chronic high-resolution imaging; Although an important technique for window creation that allows for the proper access to the brain, it is not a technique to study brain activity per se.
https://doi.org/10.1038/s42003-024-05865-8

60. Volumetric Fluorescence Lifetime Imaging Microscopy (FLIM) for In Vivo Metabolic Readouts [**I**]
High-speed volumetric FLIM approaches enable in vivo mapping of metabolic state (NADH, FAD) and oxygen-consumption dynamics across populations of cells.
https://doi.org/10.1364/OPTICA.426870

61. Total internal reflection fluorescence (TIRF) Microscopy In Vivo [**I**]
Total internal reflection fluorescence microscopy adapted for superficial cortical imaging in live animals. ***But highly niche.***
https://doi.org/10.1021/acsnano.3c04489

62. Random Access Microscopy [**I**]
Acousto-optic deflector-based rapid laser positioning for imaging distributed neurons.
https://doi.org/10.1038/nmeth.4033
https://iopscience.iop.org/article/10.1088/2515-7647/ad2e0d

63. Reflectance Imaging / Intrinsic Optical Signals Imaging [**I**]
Measures intrinsic optical signals from the cortical surface without exogenous labels. {merge with #51?}
https://doi.org/10.1016/j.xpro.2021.100779
https://doi.org/10.1098/rstb.2015.0360

64. Second Harmonic Generation (SHG) Microscopy [**I**]
Label-free imaging in live tissue, using probes. Some papers analysed brain vascular dynamics.
https://doi.org/10.1073/pnas.1004748107 *(pivotal, not brain)*
https://doi.org/10.1021/acsphotonics.9b01749 (brain dynamics)

65. Lattice Light-Sheet Microscopy [**O**]
Although it has the potential to In Vivo Imaging, it is basically an technical advance within the Light-Sheet Microscopy technique.
https://research.pasteur.fr/en/event/lattice-light-sheet-microscopy-applied-to-neuroscience-re

search/
https://doi.org/10.3390/mi10090599 (Cultures)

66. Expansion-Assisted Selective Plane Illumination Microscopy (Ex-SPIM) [**O**]
Combines tissue expansion with light-sheet imaging for super-resolution whole-brain activity mapping in fixed but activity-tagged samples. Again falls within the bigger umbrella of Light-Sheet Imaging. And not yet In Vivo ready.
https://doi.org/10.7554/eLife.91979.3

67.Digital Holographic Microscopy [**I**]
Phase-sensitive optical technique for label-free detection of neural activity-induced refractive index changes.
https://doi.org/10.1038/s41467-023-36889-z
https://doi.org/10.1016/j.conb.2018.03.006

E. Optical Indicators / Novel Sensors

65. Genetically Encoded Dopamine Indicators (GRAB-DA, dLight1) [**I**]
Used widely in vivo with fiber photometry and two-photon microscopy.
https://doi.org/10.1038/s41592-023-02100-w

66. Genetically Encoded Glutamate Indicators (IGluSnFR) [**I**]
Also capable of being used for In Vivo studies
https://doi.org/10.1038/s41592-023-01863-6
https://doi.org/10.1111/jnc.15608 (reviews on several studies)

67. Genetically Encoded Acetylcholine Indicators (GACh) [**I**]
Maps cholinergic dynamics in vivo
https://doi.org/10.1038/s41586-023-06492-9

68. Genetically Encoded cAMP/PKA/Second-Messenger Sensors [**I**]
(e.g., Pink Flamindo, G-Flamp) reflect intracellular signaling during neural activity.
https://doi.org/10.1038/s41467-022-32994-7
https://doi.org/10.1016/j.celrep.2017.12.022

69. Genetically Encoded Serotonin Sensors (GRAB5-HT) [**I**]
Monitor serotonergic transmission in behaving animals.
https://doi.org/10.1038/s41593-021-00823-7
https://doi.org/10.1038/s41592-024-02188-8

70. Genetically Encoded Norepinephrine Sensors (GRAB-NE) [**I**]
Track noradrenergic activity during behavior and cognitive tasks.
https://doi.org/10.1016/j.neuron.2019.02.037
https://doi.org/10.1016/j.neuron.2024.03.001

71. Fluorescent False Neurotransmitters (FFNs) [**I**]
Visualize neurotransmitter release and recycling, with in vivo capability.
https://doi.org/10.1021/acschemneuro.1c00580
https://doi.org/10.1038/s41467-018-05075-x

72. Genetically Encoded Chloride Indicators (Cl-Sensor) [**I**]
Monitor chloride dynamics relevant for inhibitory transmission.

https://doi.org/10.1038/s41467-023-37433-9

73. Genetically Encoded ATP Indicators (IATPSnFR) [**I**]
Track cellular energy status and metabolic activity in neurons.
https://doi.org/10.1016/j.neuron.2021.11.027
https://doi.org/10.1038/s41586-021-03497-0

74. Genetically Encoded Lactate Sensors [**I**]
Monitor lactate shuttling and metabolic coupling between neurons and glia.
https://doi.org/10.1038/s41467-025-64484-x

75. Genetically Encoded Redox Indicators (roGFP) [**O**]
Detects oxidative stress and redox-state changes, although there are In Vivo applications, they are outside the temporal dynamics that we are considering.
https://doi.org/10.1021/acschemneuro.0c00342
https://doi.org/10.1186/s13024-024-00702-2 (almost)
https://doi.org/10.3390/ijms21218164
https://doi.org/10.1038/s41596-018-0042-5

76. Genetically Encoded Nitric Oxide Sensors (geNOps and related probes) [**I**]
Fluorescent genetically encoded reporters for nitric oxide dynamics to monitor NO signaling in vivo during neural activity.
https://doi.org/10.1016/j.celrep.2023.113514

77. Genetically Encoded Potassium Indicators (GEPIs) [**I**]
Fluorescent sensors for monitoring potassium dynamics in extracellular space.
https://doi.org/10.1038/s41598-024-62993-1

78. pHluorins (pH-sensitive GFPs) [**O**]
pH-sensitive fluorescent proteins for tracking synaptic vesicle recycling. But mainly restricted to Neuromuscular Junction (NMJ) and In Vitro preparations. Limited In Vivo essays, and again, studying NMJ.
https://doi.org/10.1016/j.xpro.2022.101766
https://dx.doi.org/10.3791/67633
https://doi.org/10.1073/pnas.1112688108
https://doi.org/10.1007/978-1-59745-261-8_22
https://doi.org/10.1523/JNEUROSCI.2005-21.2022

79. Synaptophysin-pHluorin SypHy [**I**]
Synaptophysin-pHluorin fusion protein for imaging synaptic vesicle exocytosis. Although not a common tool, there are papers showing its feasibility.
https://doi.org/10.1523/JNEUROSCI.0670-07.2007
https://doi.org/10.1016/S0896-6273(04)00144-8 (clear in vivo demonstration)

80. GCamp Variants (GCamp6f, GCamp7f, GCamp8) [**I**]
Successive generations of genetically encoded calcium indicators with improved kinetics and

sensitivity. ***NOTE:*** *they are all part of the big Genetic Encoded Calcium Indicators, so they should be within a specific umbrella in the final output.*
https://doi.org/10.1016/j.neures.2020.05.013

81. Genetically Encoded GABA Indicators (iGABASnFR) **[I]**
Fluorescent sensors for real-time monitoring of GABA release and dynamics in vivo.
https://doi.org/10.1111/jnc.15608
https://doi.org/10.1016/j.ebiom.2021.103272
https://doi.org/10.1038/s41592-019-0471-2

82. Genetically Encoded Histamine Sensors (GRAB-HA) **[I]**
Track histaminergic signaling and neural modulation during arousal and behavior.
https://doi.org/10.1016/j.neuron.2023.02.024

83. Genetically Encoded Adenosine Sensors (GRAB-Ado) **[I]**
Monitor adenosine levels as a neuronal marker
https://doi.org/10.1038/s41586-022-05407-4
https://doi.org/10.1038/s41467-025-59530-7

General Observation: *These papers do a good job on summing up the Genetically encoded sensors available for In Vivo Imaging https://doi.org/10.1111/jnc.15608 / https://doi.org/10.1146/annurev-anchem-061522-044819*

F. Photoacoustic & Hybrid Techniques

81. Voltage-Sensitive Photoacoustic Imaging **[I]**
A new area combining voltage dyes with photoacoustics.
https://doi.org/10.1002/lpor.202400165

82. Nitrogen-vacancy (NV) diamond sensors **[I]**
NV diamond sensors used for in vivo magnetic-field measurements of neuronal activity. Very limited, to C. Elegans for instance. But it is applicable.
https://doi.org/10.1073/pnas.1601513113
https://doi.org/10.1038/s41598-023-39539-y

83. Multispectral Optoacoustic Tomography (MSOT) **[I]**
Provides spectral unmixing of multiple chromophores for functional brain imaging.
https://doi.org/10.1016/j.pacs.2021.100285

84. Photoacoustic Computed Tomography (PACT) **[I]**
Deep-tissue functional imaging with optical contrast and ultrasound resolution.
https://doi.org/10.1002/jbio.201700024
https://doi.org/10.1364/BOE.423707

85. Functional Photoacoustic Microscopy (fPAM) **[I]**
High-resolution imaging of hemodynamic responses to neural activity.
https://doi.org/10.1038/s41377-022-00836-2
https://doi.org/10.1016/j.neuroimage.2021.118260

86. Photoacoustic Lifetime Imaging Microscopy (PALM) [**O**]
*The PALM technique is actually **photo-activation localization microscopy (PALM)**, this seems to be an inaccuracy from the LLM, excluded then.*

87. Microbubble-Enhanced Functional Ultrasound (Contrast-Enhanced fUS) [**I**]
*Use of intravascular microbubble contrast agents to boost sensitivity and spatial resolution of functional ultrasound hemodynamic measurements linked to neural activity. **Note:** it will fall under the bigger umbrella of functional Ultrasound*
https://doi.org/10.1016/j.neuroimage.2015.09.037 (microbubble contrast)
https://doi.org/10.1016/j.cobme.2021.100286 (general technique)

88. Photoacoustic Neurotransmitter Sensing [**O**]
*Molecular imaging of neurotransmitter release using photoacoustic probes. Very borderline, pending to [**O**]. There's one paper showing its activity in the live rat cortex. And in the author's own words "In this communication, we report the first demonstration of photoacoustic voltage response imaging in both in vitro HEK-293 cell cultures and in vivo mouse brain surfaces. Using spectroscopic photoacoustic tomography at isosbestic wavelengths, we can separate voltage response signals and hemodynamic signals on live brain surfaces." This wouldn't fall very far from what #81* Voltage-Sensitive Photoacoustic Imaging ***IS***.
https://doi.org/10.1038/s41598-017-02458-w

89. Granger Causality Photoacoustic Imaging [**O**]
Combines photoacoustic imaging with Granger causality analysis for functional connectivity mapping. Although it is an interesting development, it is a post processing analysis tool, not a new technique to be taken into account.

90. Photoacoustic Elastography [**O**]
Measures tissue stiffness changes, but still does not appear to have utility within dynamic brain imaging. Or examples of it.
https://doi.org/10.1016/j.pacs.2024.100630
https://doi.org/10.1364/OL.41.000725
https://doi.org/10.1364/OL.485623

91. Hybrid Photoacoustic-Electrical Tomography [**O**]
Seems to be a hallucination from the LLM, can't find papers with these terms. There are some close, like the ones below. But that does not yet have applicability in dynamic brain imaging.
https://doi.org/10.1137/080715123
https://iopscience.iop.org/article/10.1088/1361-6420/ad4669

92. Photoacoustic Voltage-Sensitive Dye Imaging (PA-VSDI) [**O**]
The same as #81.
https://doi.org/10.1002/lpor.202400165

G. Neural Activity Through Blood Flow & Oxygenation

90. Thermal Infrared Imaging / Thermoencephaloscopy [**I**]
This specific variation of the infrared technique has some history, and has seen few studies

in the last years. But it can be characterized as a direct brain activity measuring technique.
https://doi.org/10.1038/srep17471
https://doi.org/10.1016/S0301-0082(98)00038-0
https://doi.org/10.1111/psyp.12243

91. Speckle-Modulated Optical Coherence Tomography (OCT) **[I]**
OCT-based neuronal mapping (beyond standard laser speckle imaging). The third link is the main argument for inclusion (from it other literature papers can be searched).
https://doi.org/10.1038/ncomms15845
https://doi.org/10.1063/5.0278271
https://doi.org/10.1093/cercor/bhac388 (functional OCT)

92. Doppler Optical Coherence Tomography (D-OCT) **[I]**
For real-time blood-flow-linked neural-activity measurements.
https://doi.org/10.1364/BOE.5.003217
https://doi.org/10.1021/acsphotonics.4c00856

93. Visible Light Optical Coherence Tomography (vis-OCT) **[I]**
Also able to study Brain Activity in relation to one condition vs another.
https://doi.org/10.1364/BOE.6.003941
https://doi.org/10.1364/BOE.6.001429
https://doi.org/10.1117/1.JBO.22.12.121707

94. Hyperspectral Imaging of Intrinsic Signals **[I]**
Capable of being applied In Vivo and dynamically, within our criteria. But there are just a few papers on it.
https://doi.org/10.1117/1.NPh.2.4.045003
https://doi.org/10.1007/978-3-319-91287-5_3

95. Time-Domain Near-Infrared Spectroscopy (TD-NIRS) **[I]**
Offers depth-resolved hemodynamic monitoring with improved accuracy. ***Note:*** *should be included within the NIRS hierarchy. As it is an improvement on the technique.*
https://doi.org/10.1038/s41598-024-68555-9
https://doi.org/10.1117/1.JBO.27.7.074710
https://doi.org/10.1117/1.NPh.10.1.013504

96. Functional Diffuse Optical Tomography (fDOT) **[I]**
Again a technique that relies on NIRS principles, so ***Note:*** *should be included within NIRS umbrella.*
https://doi.org/10.1117/1.NPh.6.3.035007

97. In Vivo Electron Paramagnetic Resonance (EPR) Oximetry **[I]**
Direct in vivo EPR/Electron Spin Resonance oximetry for quantitative tissue pO2 mapping and dynamic oxygen-consumption measurements. More used in the context of hypoxia and strokes. It is very niche and limited, see second link for literature review.
https://doi.org/10.1007/s12013-017-0798-1
https://doi.org/10.4103/2045-9912.202911

98. Laser Doppler Flowmetry [**I**]
Continuous measurement of cerebral blood flow/perfusion using laser Doppler shifts. Has a history of use in clinical settings, but really limited.
https://doi.org/10.1111/micc.12884
https://doi.org/10.1002/lpor.202401016
https://doi.org/10.1007/s12028-017-0472-x

99. Oxygen-15 Water PET ([^{15}O]H_2O PET) [**I**]
Quantitative cerebral blood flow measurement using positron emission tomography. Not widely used, but still a viable technique.
https://doi.org/10.1053/j.semnuclmed.2023.08.002 (review)
https://doi.org/10.1016/j.neuroimage.2013.11.044 (vs BOLD; whisker stimulation)

100.Hydrogen Clearance CBF Measurement [**I**]
Historical method using hydrogen electrodes to measure local cerebral blood flow. Fits our criteria.
https://doi.org/10.1038/jcbfm.1986.83

101. Autoradiographic CBF Measurement ([14C]iodoantipyrine) [**O**]
Ex vivo quantitative mapping of cerebral blood flow using radiotracers. Therefore, by definition, not In Vivo.
https://doi.org/10.1016/0006-8993(95)00657-C

102. Near-Infrared Fluorescence Imaging of Hemodynamics [**I**]
Uses exogenous fluorescent dyes to track blood flow and oxygenation changes in real time.
https://doi.org/10.1371/journal.pone.0048383

103.Polarized Light Imaging (PLI) [**O**]
It is a technique not applicable for In Vivo studies.
https://doi.org/10.1016/j.bpj.2020.03.016

104.Functional Near-Infrared Optical Tomography or Diffuse Optical Tomography [**I**]
Reconstruction of hemodynamic responses using near-infrared light for 3D activity mapping.
Note: *should go into the fNIRS family, but as a separate technique.*
https://doi.org/10.3390/s25072040 (review, and there are several with checkerboard stimuli)
https://doi.org/10.1038/s41598-025-85858-7

H. Behavioral + Neural Integrated Techniques

102. Neuromorphic Cameras Linked With Neural Imaging [**O**]
High-speed event-driven sensors capturing animal behavior synchronized with brain activity (not a brain technique per se, but part of modern in vivo pipelines).

103.Deep Label-Free Microscopy (DLFM) [**U**]
Uses deep learning to extract neural activity from label-free imaging of scattering changes. Uncertain, once it uses label free techniques as basis, but with improvements in relation to processing.
https://doi.org/10.1038/nm.3495

104.Acoustic Recording of Neural-Related Behavior [**O**]
Ultrasonic vocalization recording synchronized with neural activity measurements. By definition also not a distinct technique per se.

105.Eye-Tracking Integrated Neural Recording [**O**]
Combines pupil tracking with brain activity to study visual attention and processing. Although a very important physiological/behavioral measure, not a distinct technique per se regarding brain activity.

106.Pose Estimation with Neural-Activity Synchronization [**O**]
Uses AI-based body tracking (e.g., DeepLabCut) linked to real-time neural signals.
Again, not a distinct technique per se regarding brain activity.

107.Real-Time Closed-Loop Neural Decoding & Stimulation Systems [**O**]
Integrated pipelines that decode ongoing neural activity in real time and deliver contingent stimulation (optogenetic, electrical, ultrasonic) to probe causality during behavior.
Although an important tool in modern neuroscience, it can be seen as an methodological approach that uses distinct techniques, both for recording and interfering in brain activity.

108.Whisker Tracking with Neural Recording [**O**]
High-speed videography of whisker movements synchronized with neural data.
Not a distinct technique per se regarding brain activity.

109.Operant Conditioning Chambers with Neural Interfaces [**O**]
Behavioral boxes integrated with neural recording/stimulation for learning studies.
Again, not a distinct technique per se regarding brain activity.

110.Sleep-Wake Monitoring with EEG/EMG [**O**]
It is EEG and MEG. Can be associated with other physiological measures (e.g. EKG), but doesn't fit within our definitions.

111.Gaze-Contingent Neural Recording [**O**]
Integrates real-time eye-tracking with adaptive neural stimulation to study visuomotor integration. Again, not a distinct technique per se regarding brain activity.

112.Multi-Animal Social Behavior Tracking with Neural Synchronization [**O**]

AI-based tracking of social interactions in groups, synced with individual neural activity recordings. Again, a very important ecological tool in neuroscience, but not a distinct technique per se regarding brain activity.

113.Virtual Reality-Integrated Neural Imaging [**O**]
Combines VR environments with in vivo brain recordings to study navigation and spatial cognition. Excluded once it is not a technique per se, as it relies on EEG/fNIRS or others.

I. Interference / Modulation Techniques

111. Focused Ultrasound Blood–Brain Barrier Opening (FUS-BBBO) [**I**]
Used in vivo to modulate circuits or allow entry of neuromodulators. The majority of studies are measured in a time window of weeks and after repetitive stimulation. If for 'reading' brain

activity we're being strict regarding the time windows, here we should as well. But this is a problem of study design, once that the 4th study below shows the feasibility of studying its immediate response.
https://doi.org/10.1002%2Fmds.101
https://doi.org/10.1148/radiol.14140245
https://doi.org/10.1093/brain/awab460
https://doi.org/10.1038/s41598-018-25904-9 (real time response)

112.Temporal Interference Stimulation (TI Stimulation) [**I**]
Non-invasive deep-brain electromagnetic stimulation using intersecting high-frequency currents.
https://doi.org/10.3389/fnhum.2023.1266753
https://doi.org/10.1016/j.cell.2017.05.024
https://doi.org/10.1109/EMBC46164.2021.9629968

113. Transcranial Random Noise Stimulation (RNS) [**I**]
Another electrical non-invasive modulation technique that fits into our criteria.
https://doi.org/10.1038/s41598-019-51553-7
https://doi.org/10.3389/fncel.2017.00162

114. Photothermal Neuromodulation (non-genetic) [**I**]
Uses nanoparticles or infrared light to activate neurons.
https://doi.org/10.1002/admi.202400873
https://doi.org/10.1021/acsnano.4c01037

115. Infrared Neural Stimulation (INS) [**I**]
Pulsed IR light drives neural activity, distinct from optogenetics.
https://doi.org/10.1073/pnas.2015685118
https://doi.org/10.1038/s41598-021-89163-x

116. Scanning Ultrasound Neuromodulation (SUN) [**O**]
Although it is a real application and interference technique, the common term is the transcranial Focused Ultrasound Stimulation #I.127, so excluded to avoid duplication.

117. Optoacoustic Neuromodulation [**I**]
The below paper shows its capacity to stimulate/interfere within our time frames criteria.
https://doi.org/10.1038/s41467-020-14706-1

118. Iontronic microfluidic probes / microfluidic interconnection [**I**]
Microfluidic-based chemical stimulation with spatiotemporal precision, feasible for In Vivo applications, but a very limited number of studies.
https://doi.org/10.1038/s41378-021-00295-6 (feasibility)
https://doi.org/10.1002/smll.202410906

119. Transcranial Photobiomodulation (tPBM) [**I**]
Low-level near-infrared light to modulate brain metabolism and activity. Different than #I.115, and fits into our criteria.
https://doi.org/10.1038/s41598-019-42693-x

https://doi.org/10.1126/sciadv.abq3211
https://doi.org/10.1364/BOE.402047

120. Vagus Nerve Stimulation (VNS) [**I**]
Electrical stimulation of vagus nerve to indirectly influence brain circuits.
https://doi.org/10.1093/cercor/bhab158
https://doi.org/10.3390/brainsci12091137

121. Deep Transcranial Magnetic Stimulation (dTMS) [**I**]
Uses H-coil for deeper penetration than standard TMS. Should be included within the TMS hierarchy.
https://doi.org/10.5498/wjp.v13.i9.607
https://doi.org/10.1016/j.jneumeth.2021.109261 (coil for animal models)
https://doi.org/10.1016/j.jneumeth.2020.108709
https://doi.org/10.1523/ENEURO.0163-17.2018 (task in mice)

122. Closed-Loop Responsive Neurostimulation (RNS) for Research [**O**]
Implantable or external systems that detect electrophysiological biomarkers and feedback into the system. Typical Brain Machine Interfaces use this, but couldn't be considered a separate technique per se.

123. Chemical-Genetic Actuation (PSAM/PSEM) [**I**]
Pharmacologically selective actuator modules for remote neural control.
https://www.addgene.org/guides/chemogenetics/
https://doi.org/10.1523/JNEUROSCI.0625-23.2023
https://doi.org/10.1038/s41593-020-0661-3 (shows its full capacity)

124. Cortical Cooling [**I**]
Focal cooling for reversible neural inactivation to study functional localization. Really classical method.
https://doi.org/10.3389/fnsys.2011.00053
https://doi.org/10.1016/0006-8993(77)90734-X (1977 study)

125. Lidocaine Inactivation [**I**]
Local pharmacological blockade of neural activity for connectivity mapping.
https://doi.org/10.1016/S0165-0270(97)02229-2 (1997)

126. Muscimol Inactivation [**I**]
GABAA receptor agonist for reversible cortical silencing in behavioral studies.
https://doi.org/10.1016/j.jneumeth.2008.01.033
https://doi.org/10.1177/00368504221141660

127. Transcranial Focused Ultrasound Stimulation (tFUS) [**I**]
Non-invasive ultrasound waves for targeted modulation of cortical excitability.
https://doi.org/10.1007/s13534-024-00369-0
https://doi.org/10.1371/journal.pone.0288654
https://doi.org/10.3389/fnhum.2021.749162

128. Galvanic Vestibular Stimulation (GVS) [**I**]
Electrical stimulation of vestibular nerves to influence balance-related brain activity.
https://doi.org/10.1152/jn.00035.2019
https://doi.org/10.3389/fneur.2012.00117
https://doi.org/10.1016/0006-8993(82)90990-8 (1982)
https://doi.org/10.1016/j.brainresbull.2004.07.008

129. Trigeminal Nerve Stimulation (TNS) [**I**]
External electrical stimulation of trigeminal nerve branches to modulate brainstem and cortical activity.
https://doi.org/10.1186/s42234-023-00128-z
https://doi.org/10.3171/jns.2002.97.5.1179
https://doi.org/10.1007/s00221-018-5338-8

J. Emerging & Frontier Approaches

127. Bioluminescent Voltage Imaging (e.g., LOTUS-V) [**I**]
No excitation light; extremely low phototoxicity for in vivo activity imaging.
https://doi.org/10.1038/s41598-019-43897-x
https://doi.org/10.1117/1.nph.11.2.024203

128. Upconversion Nanoparticle-Based Neural Imaging [**I**]
Allows deeper brain optical readout using NIR-to-visible conversion. ***Note:*** *consider situating it within the optogenetics framework, as stimulation/interference tool.*
https://doi.org/10.1126/science.aaq1144
https://doi.org/10.1016/j.biomaterials.2017.07.017

129. Magnetothermal Neural Stimulation [**I**]
Interference/*Stimulation technique, take care to not duplicate when merging. There's no readout available for In Vivo use.*
https://doi.org/10.1038/s41467-021-25837-4 (stimulation)
https://doi.org/10.7554/eLife.27069 (stimulation)
https://doi.org/10.1038/s41563-022-01281-7 (Stimulation)

130. Molecular fMRI (m-fMRI) [**I**]
Probes coupling specific cellular signaling events to MRI contrast.
https://doi.org/10.1016/j.jneumeth.2021.109372

131. Functional Ultrasound Localization Microscopy (ULM-fUS) [**I**]
Neurova*scular mapping during activity, fitting into our criteria.*
https://doi.org/10.1038/s41592-022-01549-5

132. Neuromodulation via Magnetic Nanodiscs [**I**]
A new method of brain stimulation without the need of transgenes.
https://doi.org/10.1038/s41565-024-01798-9
https://doi.org/10.3389/fnhum.2025.1489940

133. Quantum Diamond Microscopy [**O**]
Duplicate from F.82

134. X-ray-Induced Acoustic Computed Tomography (XACT) [**O**]
Combines X-ray absorption with ultrasound detection for imaging. But still has no functional / dynamic applications that fit into our inclusion criteria.
https://doi.org/10.1016/j.pacs.2020.100177

135. Magnetic Resonance Spectroscopic Imaging (MRSI) [**I**]
*Spatially resolved spectroscopy for mapping neurotransmitter distributions, in time.**
https://doi.org/10.1002/nbm.4314
https://doi.org/10.1016/j.neuroimage.2023.120194
https://doi.org/10.3389/fpsyt.2018.00076

136. Neutron Stimulated Emission Computed Tomography (NSECT) [**O**]
Emerging technique for mapping light element distributions in neural tissue. But still not able to perform dynamic studies. An interesting tool for structural studies. Same as #J.146
https://doi.org/10.1098/rsif.2019.0186
https://doi.org/10.1038/s41598-021-92995-2

137. Holographic Optogenetic Stimulation [**I**]
Uses holography for multi-site optical neural control and readout. ***Note:*** *It should go under the greater Optogenetic Umbrella, as an important resolution advancement*
https://doi.org/10.1038/s41593-021-00902-9
https://doi.org/10.1523/JNEUROSCI.1785-18.2018

138. Nanowire Intracellular Recordings [**I**]
Nanoscale wires for minimally invasive intracellular potential measurements. This goes under the hierarchy of electrodes;
https://doi.org/10.1002/adma.202504171 *

139. AI-Augmented Functional Connectivity Analysis [**O**]
Although increasingly important. This Machine-learning-enhanced mapping of dynamic brain networks from imaging data is not a novel technique per se. It's an advancement in post processing.

140. Cryogenic Electron Microscopy for In Vivo Snapshots [**O**]
Hardly any justification for it to be included as an In Vivo technique.
https://doi.org/10.1038/s41467-024-47066-1

141. In Vivo Quantum Diamond Scalp Magnetometry (NV-MEG) [**O**]
It is still a possibility, not fully developed for Brain Activity Recordings, except for similar papers as the ones in F.82, which would characterize as a duplicate. So we should keep this out and just count the F.82 entry.
https://www.nature.com/articles/s41598-023-39539-y
https://doi.org/10.1063/5.0167372
https://doi.org/10.1038/s42005-022-00978-0

142.CLARITY with In Vivo Applications [**O**]
Tissue transformation for ***post-mortem*** *structural mapping of identified circuits.*
https://doi.org/10.1111/nan.12293

143. Expansion Microscopy [**O**]
Physical tissue expansion for super-resolution imaging, but post-mortem.
https://doi.org/10.1038/s41551-022-00912-3

144. Magnetic Resonance Phased Array Microscopy [**O**]
At least not in the terms used here. It can be a hallucination from the LLM, but if we try to infer from what the output should be, perhaps it was Ultra-High Field laminar functional magnetic resonance imaging. ***Note:*** *I'll try to put this under the hierarchy of fMRI. The link below is valuable to this discussion.*
https://doi.org/10.1093/psyrad/kkae027

145. X-ray Optogenetics [**I**]
Combining X-ray stimulation with optogenetic actuators for deep brain modulation.
https://doi.org/10.1038/s41467-021-24717-1

146. Neutron Scattering Tomography [**O**]
Emerging technique for mapping light element distributions in neural tissue. But still not able to perform dynamic studies. An interesting tool for structural studies. Same as #J.136
https://doi.org/10.1098/rsif.2019.0186
https://doi.org/10.1038/s41598-021-92995-2

147. Diamond Quantum Sensing of Neural Magnetic Fields [**O**]
Duplicate from F.82

148. Bioorthogonal Chemistry-Based Neural Activity Reporters [**O**]
Uses click chemistry to label and image active neurons, but needs to do it post-mortem (brain slices), and its application in the brain is yet very limited.
https://doi.org/10.1038/s44160-025-00815-6
https://doi.org/10.1126/science.1155106
https://doi.org/10.1002/anie.201705609
https://doi.org/10.1021/jacs.6b08894

149. Nanopore-Based Ion Channel Activity Sensing [**O**]
Implantable nanopore devices for real-time monitoring of ion fluxes in single neurons. But still can't be applied to In Vivo dynamical analysis.
https://doi.org/10.1021/acsnano.5c04662
https://doi.org/10.1186/s43556-021-00026-3

150. Terahertz Imaging for Neural Activity [**I**]
It can be used as an interference technique to study brain activity. As shown by
https://doi.org/10.7554/eLife.97444.3
DOI: 10.4103/NRR.NRR-D-23-00872