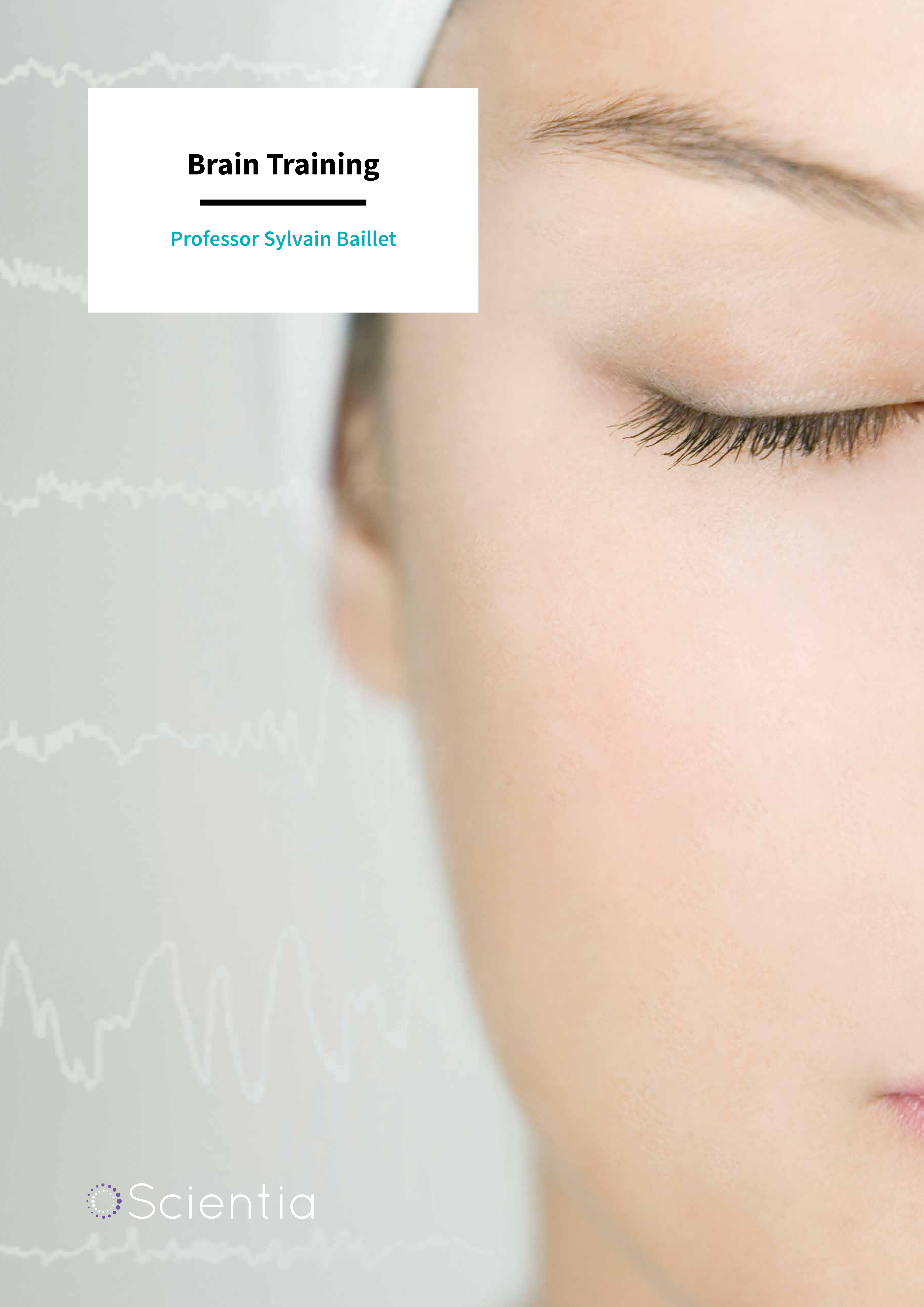


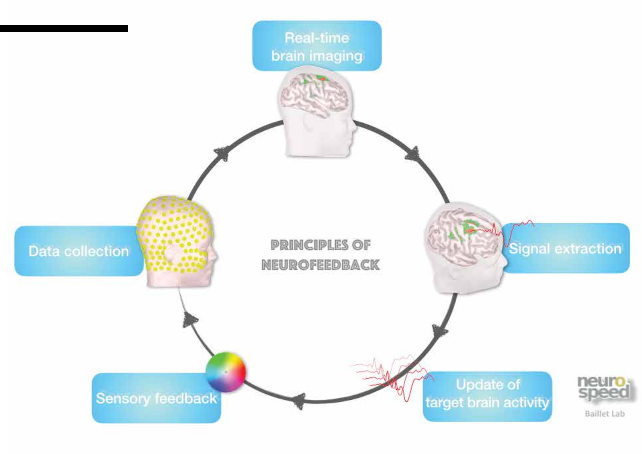
Brain Training

Professor Sylvain Baillet

Scientia

BRAIN TRAINING

Gaining insight into the brain and its inner workings improves our understanding of behaviour and our knowledge of the diseases and treatments of our most complex organ. **Professor Sylvain Baillet** and his research team at the McConnell Brain Imaging Centre of the Montreal Neurological Institute, are illuminating the brain and its functions using the latest real-time imaging technology.



Visualising Brain Activity

Over the past 40 years there have been remarkable advances in the technology developed to see the brain structures inside our heads in a safe and non-invasive manner. A range of sophisticated medical imaging instruments, Computed Tomography (CT or CAT scanner) and Magnetic Resonance Imaging (MRI) for instance, can reveal the diversity of tissues inside the body with impressive clarity.

These sophisticated imaging systems virtually cut body parts in a slice by slice manner. They then stack these slices together to form a complete three-dimensional (3D) picture of our anatomy. The disadvantage of a CT scanner is that it exposes the patient to potentially harmful X-rays. However, MRI produces images with considerably better resolution than CT. It uses a very strong magnetic field and radio waves to probe inside the body revealing the anatomy of soft tissues in great detail.

An MRI scan can also produce images related to brain function and activity. Functional Magnetic Resonance Imaging (fMRI) is a special technique used to measure local variations of oxygen consumption and blood flow related to how hard neurons are working across the brain. Functional brain mapping aims to understand how different parts of the brain contribute to certain functions.

Many psychologists and cognitive neuroscientists use brain imaging to describe brain activity when someone is engaged in a specific task. The fMRI images can show parts of the brain 'lighting up' or 'working together' when research participants perform a memory task, or listen to music, process their native or a second language, do mental calculations or engage their visual attention – just to name a few of the significant categories of tasks important to neuroscience research. For example, if a person is listening to music, then their primary auditory cortex, a region on both sides of the brain, will become active, followed by many others. The fMRI results are often represented as still images with brighter areas to illustrate activity overlaid on the anatomy of the brain.

The technique has proven very successful in revealing the brain regions involved in a great diversity of tasks. Yet, its main limitation is the fact that brain activity is poorly resolved in time. fMRI signal fluctuations are related to the physiology of blood flow and oxygenation, which is considerably slower (typically a hundred times slower) than that of neural activity. Other techniques that record brain activity on a faster time scale include electroencephalography (EEG) that measures and records 'brain waves'. These waves are electrical fluctuations in brain activity and are frequently used to help diagnose diseases such as epilepsy, sleep disorders and brain injury. EEG is a very valuable and inexpensive tool for doctors, however, it does not give a precise location of the brain regions activated during a task.

Indeed, the anatomical origins of brain wave patterns are tricky to interpret as the signals are distorted as they pass through the head tissues, especially the skull, before being recorded by electrodes that are placed on the skin surface.

Just imagine if we could record images of brain activity at superfast speeds and let the person watch this activity on a computer screen. Imagine if they could then control a pre-determined aspect of their own brain activity, as a cerebral workout exercise, using brain-activity information being fed back to them in real-time?

That's exactly what Professor Baillet and his team of researchers at McGill University are developing with a technique called real-time magnetoencephalography (MEG). They are using MEG imaging to expand and study the efficacy of a range of techniques that may allow people to 'train their brain', based on real-time, objective measures of

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their own brain activity. His goal is to understand how such neurofeedback techniques work, what the actual physiological effects are, if any, and how they can be translated efficiently and rigorously to clinical interventions, and consumer electronics products for brain wellness.

MEG: How it Works

The brain is composed of tens of billions of cells called neurons – these are linked together by cable-like fibres called axons. Fast electrical impulses are passed between brain cells along these fibres, as communication signals. When these signals converge at a certain brain location, they accumulate and trigger the cellular computation of information by the brain.

The electrical currents generated by neurons are around a nanoampere (a billionth of an Ampere). The kettle in your home may use about 10 Amperes to boil water for a cup of tea. An electrical current produces a magnetic field – the strength of the magnetic field is measured in a unit called a Tesla. For instance, the Earth’s magnetic field measures 0.05 mT (milliTesla) at the equator, and a typical clinical MRI scanner has a field strength of 1.5 to 3T.

The magnetic flux generated outside the brain by these tiny electrical currents is between 10 and 100 million times smaller than the Earth’s magnetic field. Incredibly, these very small magnetic signals caused by the electrical signals deep inside the brain can be measured using sophisticated measurement technology. The vast majority of MEG instruments include Superconducting QUantum Interference Devices (SQUIDs). These sensor devices are cooled to a few degrees above absolute zero, or −269°C, using liquid helium. At this temperature, the SQUID becomes superconducting, meaning the device has no electrical resistance. Therefore, the device has the best sensitivity for detecting small magnetic fields without being compromised by thermal noise in the sensing electronic circuits.

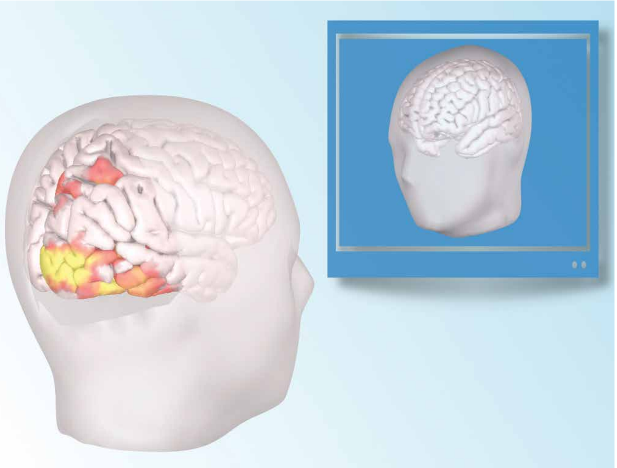
A SQUID operates continuously, and so it can measure the fastest brain activity. MEG sensing technology is currently seeing a lot of exciting innovations – new cost-effective approaches, potentially not requiring sophisticated absolute-zero cooling, are being developed and tested. They hold the promise of more accessible, more flexible and versatile, possibly wearable, MEG imaging in the near future.

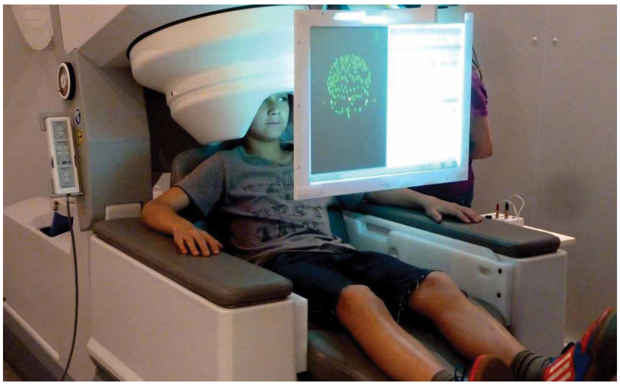
Brain Signals that Train the Brain

Training to perform a task to a high degree of skill takes a lot of practise and repetition. This applies equally to the study of mathematics or performing in sports and music. People who have developed a functional disability in speech or walking after a brain injury, such as that caused by a stroke, can re-learn or develop new skills through personalised learning strategies. Current intervention strategies often involve learning to compensate or to find ways to work around a disability or learning difficulty. ‘Our main objective is to enable people to train specific regions of their own brain, in a way that relates to a particular function, or a clinical condition. For example, we hope to see people with epilepsy able to train their brain to reduce the occurrence of seizures,’ says Professor Baillet.

Neurofeedback encompasses various methods for training specific parts of the brain relevant to learning a task or skill. Previous research using EEG has shown potential for this technique, coupled with real-time analysis of brain signals, to provide timely feedback to participants about specific aspects of their brain activity. One major issue with EEG apparatus though is that signal quality can be severely degraded by body and eye movements, or just by the fact that the contact of the EEG electrode with the skin can become loose. Poor signal quality means poor effectiveness and specificity of the procedure.

Professor Baillet’s lab has developed the





technology and expertise for MEG to provide real-time feedback to participants so that they can learn how to modulate specific aspects of their brain activity in pre-determined brain regions by receiving sensory feedback from the MEG machine. The audio or visual feedback provided can come in different flavours – from simple tones or coloured shapes, to more elaborate video games – the goal is always to encourage participants to do better towards a specific objective, using reinforcement learning strategies that reward progress to reaching the target objective.

The definition of these target signals and their anatomical origins is an active field of research – they need to be specific to the participant and the objectives of the training. For neurofeedback to become truly effective for wellness and for clinical purposes, its signal targets need to be rigorously validated, ideally using the same strict testing protocols as those for evaluating the treatment efficacy (and side effects) of new drugs beyond placebo.

To perform neurofeedback using MEG the subject sits within the machine, under a helmet that contains three hundred SQUID sensors. Signals are recorded continuously, and they are transferred to a specialised computer system for real-time processing. In one of Professor Baillet's experiments, the task involved the subject viewing a coloured disk on a computer screen and mentally changing its colour.

There is no manual for participants to change their brain activity in a predetermined manner. For neurofeedback to be successful, the person learns by trial and error, navigating different mental states and adjusting to the immediate feedback provided. Humans are particularly good at acquiring this skill via multiple training sessions, just like any new skill.

Early results from Professor Baillet's research have shown that, using real-time MEG, targeted brain regions adopt the patterns of brain activity that were aimed for after seven to twelve short training sessions. His team also reports that such modifications with training do not affect other brain regions, making the training anatomically specific. Professor Baillet says, 'the remarkable thing is that with each training session, the training program helps subjects reach their next target aim faster, with the bar being raised for each new session, in the same way you raise the bar in a high jump competition.'

These results point the way forward for future research, especially the effect of such training on actual task performance in working memory, reading or sustained attention for instance. If the method is proven effective, translation to portable EEG solutions are next, with high-quality electrodes harnessed to the computing power of smart phones or even cloud technology.

New Technologies Arising from the Research

Alongside these exciting developments in brain imaging using MEG, Professor Baillet and his team are actors at the forefront of open science. They provide other international researchers access to their custom-made software called 'Brainstorm' (http://neuroimage.usc.edu/brainstorm/). This free, open-source application is used for MEG, but also EEG and any form of multimodal electrophysiology data, for advanced analysis and visualisation.

Brainstorm has a research community of more than 17,500 registered users worldwide. More than 700 journal articles were published by Brainstorm users over the past 6 years. Professor Baillet's research group has also established the Open MEG Archives, a free and open library of MEG and other brain related data (https://www.mcgill.ca/bic/resources/omega). They started this data repository as there were very limited open resources of MEG data available to other researchers. Sharing data helps to standardise research experiments and enables the reproducibility and generalisation of scientific results for scientists and the public across the world. The archive includes related MRI and demographics data for volunteers and patients and is continuously expanding. Follow the links for more information about these open-science initiatives.

Future Direction

This research paves the way to use MEG both as a diagnostic tool and a novel treatment technique for patients. The team has had success with identifying the locus of seizures in severe cases of epilepsy and can see great potential for working with patients who have stroke, dementia, movement disorders or chronic depression. However, further careful research is needed to determine the actual benefits of interventions of this kind over and above the placebo effect – the positive benefits provided by simply believing that the therapy is working.

Professor Baillet's claims that, 'we need to investigate further the mechanisms and principles of neurofeedback – a process by which people can see on-going physiological information that they aren't usually aware of, in this case, their own brain activity, and use that information to train themselves to self-regulate. Our ultimate hope and aim is to enable patients to train specific regions of their own brain related to their condition and help them recover lost functions in a more personalised manner, faster. There are also considerable uncharted possibilities to improve healthy brain functions for learning, attention, the management of stress and sleep. In principle, the possibilities are endless.'

Meet the researcher

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Professor Sylvain Baillet is professor of Neurology and Neurosurgery, Biomedical Engineering, and Computer Science at the Montreal Neurological Institute (MNI) at McGill University in Montreal. A neuroimaging physicist, he obtained his PhD in Physics from the University of Paris, in 1998. He was a Research Associate at the University of Southern California and became principal investigator with the Centre National de la Recherche Scientifique in France from 2000–2008. He then became the inaugural Scientific Director of the magnetoencephalography (MEG) program at the Medical College of Wisconsin, US. He joined McGill University in Montreal in 2011 and founded their MEG research program and core imaging platform. In 2013-2017, he was the Director of the MNI's McConnell Brain Imaging Centre. Dr Baillet has a track record in leading multidisciplinary research projects and operations in neuroimaging and neuroinformatics, in Europe, the US and Canada. Professor Baillet's research work in systems neuroscience aims to understand the dynamical mechanisms of brain activity and functions on multiple scales and to develop detection of early manifestations of disease.

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