

# Brain.fm

## Theory & Process

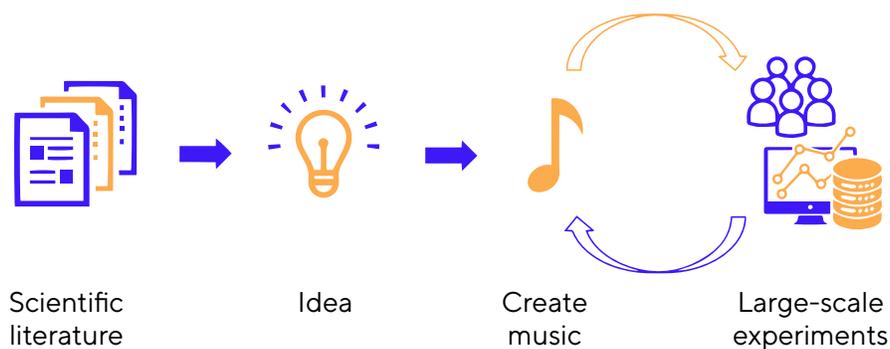
*At Brain.fm we develop and deliver functional music, directly optimized for its effects on our behavior.*

*Our goal is to help the listener achieve desired mental states such as focus or sleep.*

Music is a potent phenomenon in human auditory perception and cognition. Music can make us laugh or cry. It can spark us awake or put us to sleep. But can we purposefully design music to help us reliably shape our behavior?

At Brain.fm, we first draw on neuroscience and perceptual psychology to develop hypotheses about what kinds of sounds could be useful—to help us study, to push us in a workout, to get us to sleep, or any number of other possible functions.

Then, we create and test these sounds on a massive scale, to find out what works. This two-stage process (hypotheses followed by testing) allows us to efficiently discover functional music by cutting down the space of possibilities before testing.



This kind of process seems obvious in science, but in functional music it is rare. Some do not test their music (left three icons only, or just the middle two), while others attempt a purely data-driven approach (right two icons only).

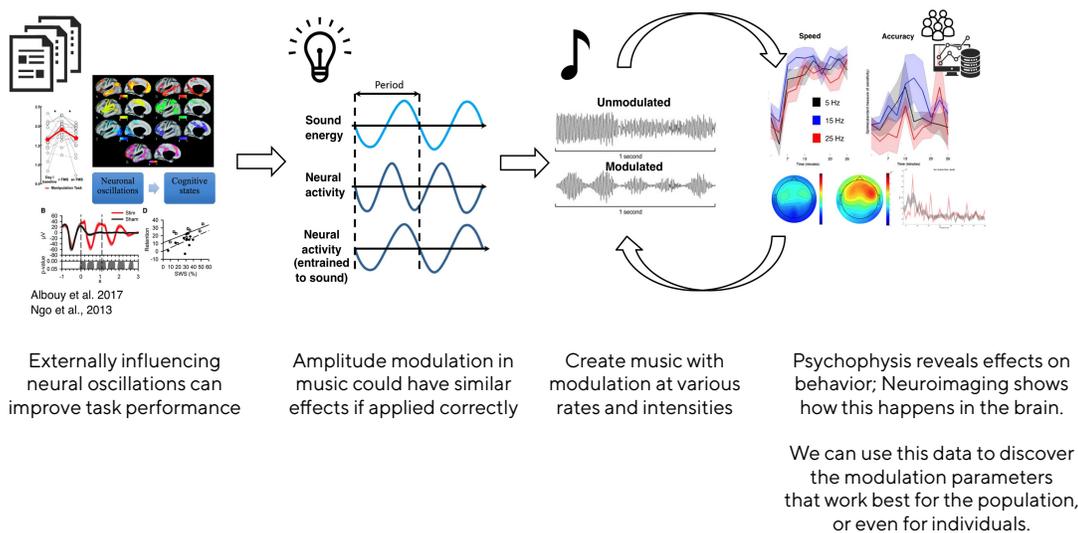
We can apply our process whenever basic research turns up a promising lead on how some aspect of sound might shape our behavior.

We have already followed several lines of evidence this way, through to their successful application in music. More lines are being worked on, and more will follow after that. As long as we keep learning about the mind and brain, this process can be used to translate the latest findings into something people can use, driving innovation in functional music.

### Example: Neural oscillations

Populations of neurons can synchronize their activity, perhaps to communicate across distant brain regions or to better perform computations (Buzsaki, 2004). Neural oscillations thus correspond to a critical middle ground linking single-neuron activity to behavior, and patterns of oscillatory activity across particular neuronal networks can be seen as fingerprints of cognitive processes (Siegel & Engel, 2012).

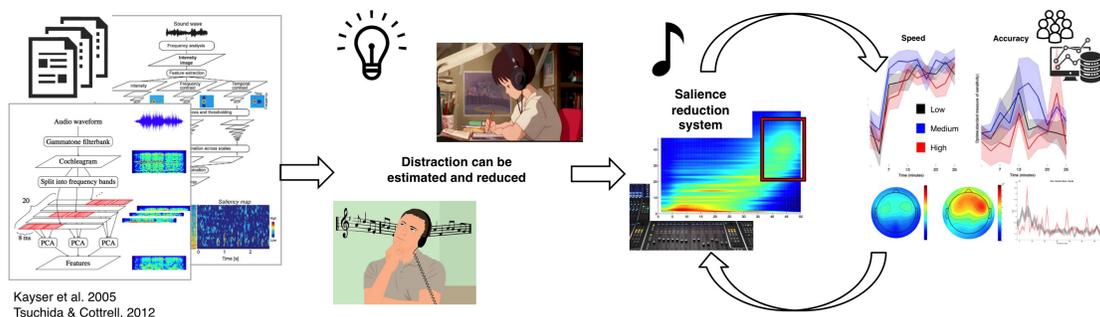
Recent work has shown that modifying ongoing oscillations can improve cognitive performance (Albouy et al., 2017; Ngo et al., 2013). This comes from experiments in labs using methods that are costly and cumbersome (like magnetic stimulation). But we also know that sound can modify neural oscillations (Luo & Poeppel, 2007; Doelling & Poeppel, 2015), and in sleep research simple acoustic stimuli like clicks and pink noise have been used to drive slow-wave activity, producing benefits to deep sleep and memory retention (Papalambros et al., 2017).



This knowledge has critical implications for sound design. Perhaps the influence of acoustic modulation on oscillatory activity could be used to great effect if this was done deliberately. After iterating between creating and testing music we have found several regimes in which this seems to be true. A particularly strong finding was that beta-rate modulation (12-20Hz, between beats and roughness) appears effective for reducing attentional lapses, and this is now a core part of Brain.fm's **Focus** music technology<sup>1</sup>

### Example: Saliency and distraction

Sounds can grab our attention, even when we don't want them to. If we can understand and predict this effect ('auditory saliency'), we can make better Focus music by ensuring that distracting moments don't appear. We've actively pursued several strategies based on saliency modeling work and ideas about bayesian surprise (Kayser et al., 2005; Tsuchida & Cottrell, 2012). The result is an in-house system to reduce saliency, distinguishing our music from most other music which, made as entertainment, is meant to grab your attention.



Surprising events grab our attention (i.e., distract). This can be estimated from the sound signal!

Most music is made to grab our attention. But for focus-music, we should estimate distraction and remove the elements that cause it.

Create an automated system that checks to ensure sound elements are not too surprising.

Psychophysics reveals effects on behavior; Neuroimaging shows how this happens in the brain. We can use this data to tweak our saliency-reduction system, and consistently make music that is neither dull nor distracting.

<sup>1</sup>This work is supported by NSF-STTR 1720698, a government grant to Brain.fm.

Our system ensures that musical structure is free of gaps, breaks or sharp changes that are likely to cause distraction. The textural density of the sound (e.g. type and number of instruments) is not permitted to change too suddenly, and many additional measures are taken to ensure that attention-grabbing elements are subdued or removed.

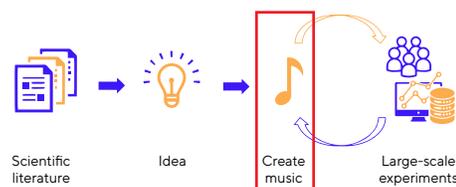
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The two lines of work above contribute to the effectiveness of our current Focus music, but many other lines of work are progressing within Brain.fm. Here are some that have already influenced our music:

- Driving slow-wave activity during Sleep
- Habituation (e.g., if music is too fully ignored, does it lose effectiveness?)
- Spatial location, movement (e.g., can auditory location manipulate visual attention?)
- Familiarity (e.g., does one's personal history with sounds make a big difference?)

In each of these cases there remains much more to learn, but we have already found ways to use what we know to improve functional music.

## How do we make the music?

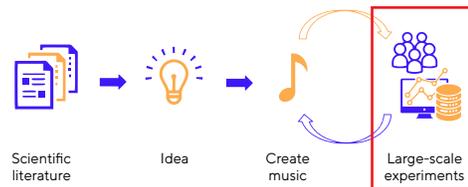


Humans compose the musical content (the Art: melodies, harmonies, chord progressions, sound design, instrument choices, etc.) We have found no substitute for the talent of brilliant musicians in laying the foundation for a new piece of music.

Then, a patented algorithmic system (A.I.) arranges these motifs over long timescales, and adds the acoustic features which constitute our core technology (the Science: modulation to alter brain activity, 3D spatialization, salience reduction, etc.)

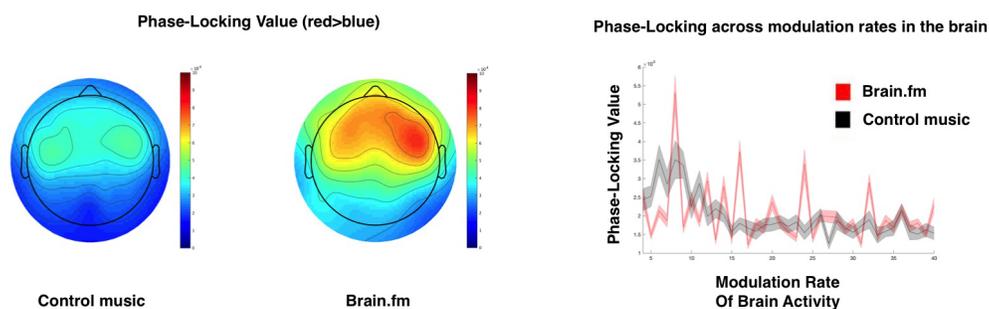
Finally, compositions are assessed by human listeners in-house and tweaked or discarded if necessary, and are tested via large-scale experiments to ensure they have the properties required to help listeners attain and sustain desired mental states over long periods of time.

## How do we run experiments?



To test our ideas we rely on experiments measuring both behavior and the brain. We run large-scale behavioral experiments using innovative methods to ensure data quality (Woods et al., 2017). Easy access to good data allows us to run detailed and useful experiments. For example, we often test music specially generated to differ only in one aspect, so that behavioral differences can be attributed to that difference. This is a direct way to learn how sound features affect behavior.

We want to understand how the brain effects these differences, so we use neuroimaging to look at brain activity in time (EEG) and space (fMRI). This often allows us to make distinctions that behavioral tests might not, since neural activity may not rise to the level of behavior. For example, our experiments using beta-rate modulation for focus music found that neural populations were phase-locking (synchronizing) to a much greater degree when given music with fast modulations and a particular modulating waveshape.



Behavioral results suggested this music did help people over time, but the differences in the brain appeared first, were easier to see, and verified that the experimental manipulation (added modulation) was having a measurable impact on brain activity beyond auditory cortex.

### Additional competitive advantages

The science-based data-driven approach described above is Brain.fm's main advantage, but several others aspects of Brain.fm are unique and highly valuable:

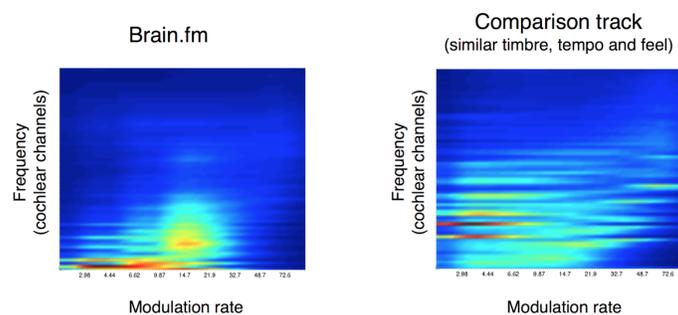
**Algorithmic music generation** (with human-in-the-loop to ensure aesthetic value) allows sounds to be created rapidly and efficiently, and to required specifications. Parameterization in the generative process allows the tracks to be described with a relatively small set of numbers, constraining variables to a space of reasonable dimensionality.

**3-D externalized sound:** We utilize 3-D spatial audio techniques involving generalized head-related transfer functions (HRTFs) to create the illusion that sound is coming from your environment (“externalized sound”), rather than inside your head. For example, sounds can appear out in front of the listener, attracting their attention to a task in the real world at that location.

**Individualized content generation (under development):** Brain.fm music could easily become more effective by exploiting user feedback to adjust the parameters of sound generation, so that with continued use each listener comes to receive tailor-made stimulation. This kind of ‘radical personalization’ is hard for art-music (radio, pop, etc.), but for functional music this is useful and feasible. This feature is under development for 2019.

**Directly optimizing sound for effects on behavior:** Most functional music services rely on pre-existing music. The individual tracks on those lists were created by musicians unlikely to optimize explicitly for effects on behavior—these tracks just coincidentally happened to have functional qualities. Other services use natural sounds or white noise, which are not optimized for aesthetic value, but are also not optimized for any other function. Brain.fm directly optimizes sound for the function at hand (working out, sleeping, etc.), while still creating great sounding music!

**Acoustically unique music via patented production tools:** Instead of relying on live musicians to create exactly the right sounds, we instead use purpose-built digital music systems (proprietary and patented) to shape the music and ensure that it conforms to the acoustic specifications we intended. For example, in our Focus music, we use rapid modulations of 10-20 ‘notes’ per second which can be precisely applied only through a system like this. As a result, Brain.fm sounds and feels different than other music.



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