# *SONIFICATION OF THE TOHOKU EARTHQUAKE*: MUSIC, POPULARIZATION & THE AUDITORY SUBLIME

*R. Michael Winters & Gil Weinberg*

Music Tech Sonification Group
Georgia Tech Center for Music Technology (GTCMT)
Georgia Institute of Technology, Atlanta GA
mikewinters@gatech.edu

## ABSTRACT

The past century has witnessed the emergence of expressive musical forms that originate in appropriated technologies and practices. In most cases, this appropriation is performed without protest—but not always. Carefully negotiating a space for sound as an objective, scientific medium, the field of sonification has cautiously guarded the term from subjective and affective endeavors. This paper explores the tensions arising in sonification popularization through a formal analysis of *Sonification of the Tohoku Earthquake*, a two-minute YouTube video that combined audification with a time-aligned seismograph, text and heatmap. Although the many views the video has received speak to a high public impact, the features contributing to this popularity have not been formalized, nor the extent to which these characteristics further sonifications' scientific mission. For this purpose, a theory of popularization based upon "sublime listening experiences" is applied. The paper concludes by drawing attention to broader themes in the history of music and technology and presents guidelines for designing effective public-facing examples.

## 1. INTRODUCTION

*Sonification of the Tohoku Earthquake* was a YouTube video uploaded nine days after the March 2011 Tohoku Earthquake in Japan. The earthquake was accompanied by a powerful tsunami that killed thousands of people, caused billions of dollars of infrastructure damage, and untold environmental catastrophe. A chilling "natural" phenomenon, the geophysical event was captured digitally using seismometers and quickly made available online. The decision to represent it using sound—as the creators intended—gave deep expression to the destructive powers of our planet's natural processes.

In sonification, the case of music is often problematic. In principle, sonification welcomes interdisciplinary perspectives and insights, yet musical or aesthetic listening practice admittedly does not coalesce smoothly with an objective, scientific mission. Efforts to construct definitions for the field echo this sentiment [1]. Musical appropriation is positioned as a fringe case, or not proper sonifications at all.

Discussing objectivity and aesthetics as a battleground between two opposing forces is not fitting. Positioning it as a scale in need of balancing is only a slight improvement. The full cultural capital of sonification may be determined by the extent to which it can transgress traditional epistemological dichotomies. Towards this goal, researchers have argued against differentiation [2], for transcendence [3], for listening-centered design [4], and for application in music research [5].

*Tohoku* was not intended as a "musical" piece. It was never meant to be performed in a concert hall, and many viewers undoubtably left before the piece played to completion. Its popularity[1] however speaks volumes to the power of sonifications that "transcend scientific or artistic practice" [3]—sonifications that pour forth from broader socio-historic relations of listening rather than a specialized scientific initiative. If an when a "killer application" does arise, it may not be scientific, and may instead arise in the context of music or popular culture [6].

This paper analyzes *Tohoku* using frameworks derived from music, philosophy, and science popularization. After identifying *Tohoku* in a history of auditory seismology, this paper situates itself in a broader context of sonification popularization and "sublime listening experiences" [7]. *Tohoku's* formal content is presented using a tailored visual score and supplemented by video content analysis. This detailed approach allows a critique of aesthetic decisions according to the following three questions:

1. What features contribute to *Tohoku's* popularity?
2. What about *Tohoku* offers experiences of the sublime?
3. Is *Tohoku* a "success" for the sonification community?

A discussion follows that identifies characteristics contributing to popularity without detracting from scientific legitimacy. The topic is then abstracted to trends in contemporary music whereby sonification and specifically *Tohoku* are at home. This discussion contributes to an ongoing dialog on the relationship of sonification and music [8], and the extent to which their research agendas can be "mutually beneficial" [5].

## 2. SEISMOLOGY, POPULARIZATION, AND THE AUDITORY SUBLIME

Earthquakes are a natural geophysical phenomenon created by a release of energy on the earth's crust and producing seismic waves that travel along its surface. Although the waves themselves travel at frequencies well below the human threshold for perception,

[1] 47K+ views: the most of any sonification-titled video on YouTube.

sounds produced as a result of these waves have a rich history, inspiring collection and categorization [9]. Recently, sound reproduction technologies have been applied to listening to the previously inaudible seismic waves [10, 11, 12]. These researchers have approached sound as a unique medium for representation, viable as a functional tool and capable of "challenging the epistemic power of the eye" [12, p. 229].

The functionality of auditory seismology is balanced by a history of aesthetic reflection [13]. For example, the naturalist John Muir recalls being suddenly awoken, both glad and frightened, by a sound "inconceivably deep and broad and earnest, as if the whole earth, like a living creature, had at last found a voice and was calling to her sister planets" [14, p. 263] (as quoted by Kahn [13]). Muir's allegorical impression of the Inyo Earthquake of 1872 highlights a powerful emotion whereby the terrifying is overcome by an estimation of inconceivable greatness and power. Though perhaps sharing many features with what might be termed "beautiful," it is differentiated as being worth of fear, carrying it to a new plane altogether. The emotion elicited by estimation of inconceivable greatness and power has been termed "the sublime" [15, 16].

The scientific arm of sonification has largely concerned itself with the first case—the use of sound production as a tool for producing new data insights. Although sound can not be "seen," this does not necessarily disavow it from scientific method, functionality or objective knowledge. In spite of the way non-speech audio usually occurs in music, listening is not merely capable of arousing emotions and aesthetic appreciation.

This ongoing struggle in the community for scientific credibility has received recent attention in the work of Supper [17]. Within the so-called "hierarchy of the senses" [18], Supper states that the field of sonification acts as a "breaching experiment" that "challenges conventions of scientific representation" [19, p. 26], while seeking a place in the prevailing doxa [20]. The notion of "challenging" in this case might be re-termed *expanding*. In contrast to a static, stale, and pure representation of data, expanded scientific convention may invigorate data through sound and appeal to experiences that defy strictly quantitative measurement.

In the pursuit of this goal, sonification has been appropriated into what might be considered more "traditional" functions of organized sound. Artistic practice [2] and science popularization [7] are two such areas. For example, instead of experts listening to to extract hidden information about a complex dynamic process, non-specialists listen and react emotionally or aesthetically without acquiring deeper objective knowledge per se. These expanded listening practices occur in social and cultural contexts (e.g. concert halls, online), and draw value not from data relationships, but from the *meaning* of the work, which may be mediated by an artist, scientist, or publicists' interpretation. For example, science popularization writers often leverage interpretations that leverage any and all facets of the social and cultural context. Audiences may be drawn to 'exotic,' 'mysterious,' or 'eerie' sounds [7], and it is not uncommon to draw upon musical metaphors.[2][3]

One thought for the way that science writers attract audiences is by appealing to the sublime. Supper has demonstrated how in various scientific fields, publicists have used sonification to construct and advertise "sublime listening experiences" [7]. They occur most often for phenomenon that have traditionally been associated with the sublime (e.g. astronomy, volcanoes, earthquakes), but may also happen in the small (i.e. genetics). Listening is proffered as a unique, immersive and visceral experience that frequently draws upon social and cultural conceptualizations of sound. Although this type of popularization may lead to many listens, the type of listening (e.g. non-specialist, affective) may do little, or even counteract the objectivity of sonification in the public's mind.

This paper makes explicit the "sublime listening experiences" theory, and approaches the subject from the ears of the listener rather than from the written words of the communicator or advertiser. Do listeners actually have sublime listening experiences? What if anything contributes to this possibility? Can sublime listening experiences be compatible with sonification's objective, scientific mission?

As with other sound producing technologies, it may be necessary to teach how to listen, or what to listen for [21]. The popularization of *Tohoku* can not be explained solely by "sublime listening experiences," and there are additional requirements originating in the preparation of the listener. The following sections analyze the form and content of *Tohoku* as source material for a subsequent analysis.

## 3. TECHNICAL & AESTHETIC CONTEXT

To understand the technical side of the piece, one must first realize that the so-called "sonification" is not a sonification, but an audification [22]. Audification is a process whereby a previously inaudible signal is made audible by direct transformation into an acoustic pressure wave in the audible domain [23]. In the case of seismographic signals—those originating from the fluctuations of the earth—frequencies below 1Hz are common. At any magnitude, the corresponding changes in pressure waves are too "deep" or "low" to be heard. To make this data audible, the creators compressed a seismographic signal in time, making it exactly 1440 times shorter in length. Perhaps not coincidentally, this transforms one day of data into one minute of audio.

This decision is one of three that might characterize an otherwise aleatoric form. The second—much less important than the first—is the simple transformation of amplitude of the signal to fit in an audio buffer. The result of this transformation is simply a change in loudness with otherwise no changes in frequencies. The third is the spatialization of the signal. In this case, four seismographic signals (three in Japan, one in Russia) are spatialized between the left and right stereo channels.

Seeing how little was done to create the audio, it may be more insightful to highlight what was not done. In his chapter in *The Sonification Handbook* [22], Dombois lists other techniques available to an audification designer. In addition to transposing the signal to a perceptually desirable frequency range by resampling, one can also *filter* to minimize uninteresting components and highlight those that matter. If the dynamic range of the signal means that the difference between loud and soft is too great or small, one can use dynamic *compression* or *expansion*. In some cases, it might be useful to *time-reverse* a signal, or add *reverberation*, though in general techniques that add new frequencies should be avoided. The *phase vocoder* [24] is the last tool Dombois recommends, and it is useful insofar as it lets the designer independently adjust pitch and speed. It may be advantageous to change the pitch without

[2] E.g. "Using the Sun to Make Music" https://www.youtube.com/watch?v=kcqiLvHiACQ. Date accessed : December 5, 2014.

[3] "Singing Comet Detected by Rosetta Is Pure Science Weirdness" http://www.huffingtonpost.com/2014/11/13/singing-comet_n_6150246.html. Date accessed : December 5, 2014.

changing the playback speed, or on the other hand, to change the speed without adjusting the pitch.

The analysis of their compositional decisions is not complete without analyzing another possibility for transforming the seismographic signals in to sound—that of parameter mapping sonification (PMSon) [25]. By contrast to audification, PMSon treats the data signal not as an acoustic signal, but as a set of instructions to be applied to the control parameters of another sound producing object. This object can be an acoustic, electronic, or digital instrument, or a collection of such sound-producing objects like an orchestra.

The parameter mapping approach was used by Marty Quinn for his *Seismic Sonata*.[4] Like *Tohoku*, the "sonata" uses seismographic data, in this case from an earthquake that occurred in California in 1994. Instead translating the data directly to an acoustic pressure wave, Quinn maps the seismographic signal to a collection of 45 discrete pitches based upon a C-major scale and plays these pitches with a piano and oboe. To draw attention to important places in the data, Quinn uses additional orchestral instruments such as plucked strings, bells, low sustained strings, and a timpani drum.

Instead of compositional complexity—created by additional signal processing or parameter mapping—*Tohoku* is marked by its stark absence. By representing the fluctuations of the earth's surface directly, and drawing the listeners attention to an aspect of nature that might otherwise be unheard, the piece might be linked with contemporary musical practices of soundscape composition and acoustic ecology [26]. Instead of using a microphone however, the composition arises from a seismometer, a technology that was not designed for sound recording or production, but has been reappropriated for an aesthetic purpose. Using this technology, *Tohoku* exposes the listener to the raw timbre of the earth's surface as it bursts, buckles, and purges its way to a new stasis. The resulting experience can be characterized by a purity of sound, a clarity that would degenerate with further sound processing or mapping. Within the audification aesthetic, unessential sonic additions must be avoided as they would amount to creative anathema.

## 4. FORMAL CONTENT

The piece begins with a bang—literally and explicitly. In fact, as the title suggests, this piece is really about this one bang, which serves as an exposition and introduction of the listener to the formal content. The material that follows this initiation—the next 1.5 minutes of the piece—is a continuation and resolution from this first explosive nightmare.

### 4.1. Visual Score

To study and present the unfolding of the earthquake in time, the first minute of the piece was transcribed as a musical score.[5] Instead of a cartesian conception, the score uses a polar coordinate system with time directed radially outwards from the center of the canvas. Although in traditional western music notation, a piece is often scored linearly, facilitating a clear trajectory of the piece from beginning to end, this was not chosen for the visual score. In these pieces, musical emphasis is typically distributed throughout a piece, with the conclusion being often just as important as the beginning. This is not the case for *Tohoku*. On the contrary, what is important about this piece is the shattering surprise of the first quake. As the score suggests, as time approaches infinity, events become less frequent and more dispersed. Although the score focuses on the first minute, *Tohoku* lasts two minutes total. There is not a precise ending, just a moment the creators chose to stop listening.

Following the initial shock, the earth continued to shake but with less intensity. The presence of earthquake-like single events after a big earthquake are called aftershocks. Although less important than the initial quake, they are the acoustic events that describe the piece until its conclusion. Though at first hardly differentiable from the major quake and mostly contributing to its monstrous, unified timbre, as time stretches away from the initial quake, they become more discernible. They occur randomly in time, intensity, and spatial location and always occur in the midst of a noise resembling the cracking of wood under pressure.

To create Fig. 4.1, the exact timings of salient aftershocks were recorded and positioned on the canvas randomly except for cases in which the timbre, spatial location, or timing was a salient descriptor. When timbre was salient, it could be described as lower or higher than the other aftershocks. When spatial location was prevalent, it was usually located to the right of center. When timing was salient, the occurrence of multiple aftershocks in a short period of time gave the impression of an echo, or closeness in their relationship. On the score, each aftershock is represented by a circle whose radius is determined by the loudness of the event, and whose foci represents the exact position of the quake in time, radially from the center of the canvas. When timbre or spatial location was salient, this was used to determine the position on the canvas (up/down→high/low timbre, left/right→left/right stereo position) along the exact radial position.

Aftershocks occur with all manner of magnitude and those that were included in the score as circles were those that were the strongest. The events that were not audibly differentiable yet nevertheless contributed to the timbre are notated as red lines radiating outwards from the center of each aftershock and ending abruptly with a crack. These cracks were too many in number to be counted, and thus they are portrayed in density rather than precisely in time. These aftershocks occur with diminishing frequency until the end of the analysis.

### 4.2. Stasis

A somnific character enters 37.5 seconds in to the analysis: the return of faint broad-band noise to the signal. For the listener, it may not be clear why this happens, or what this corresponds to. However, on careful auditory analysis, it is strikingly similar to the noise heard at the beginning of the piece, before the first quake occurred. The physical correspondence of this event is not clear (and may even be evidence of prior low-pass filtering), but the similarity of the two temporally displaced sounds is notated in the score through the color orange.

Orange represents stasis, or the presence of normalcy. For the first 6.5 seconds of the analysis, there is a faint rustling noise. This precludes the first quake, and provides context whereby the listener can determine what "peaceful/uneventful" sound is like. The return of this sound towards the end of the piece is marked by a circle at 37.5 seconds and wavy orange lines continuing until the conclusion of the piece.

Each aftershock includes orange in its center between the foci

[4] http://www.drsrl.com/seismic.html Accessed: September 24, 2014.

[5] Actual timings start at 00:08:50 and end at 01:08:50.

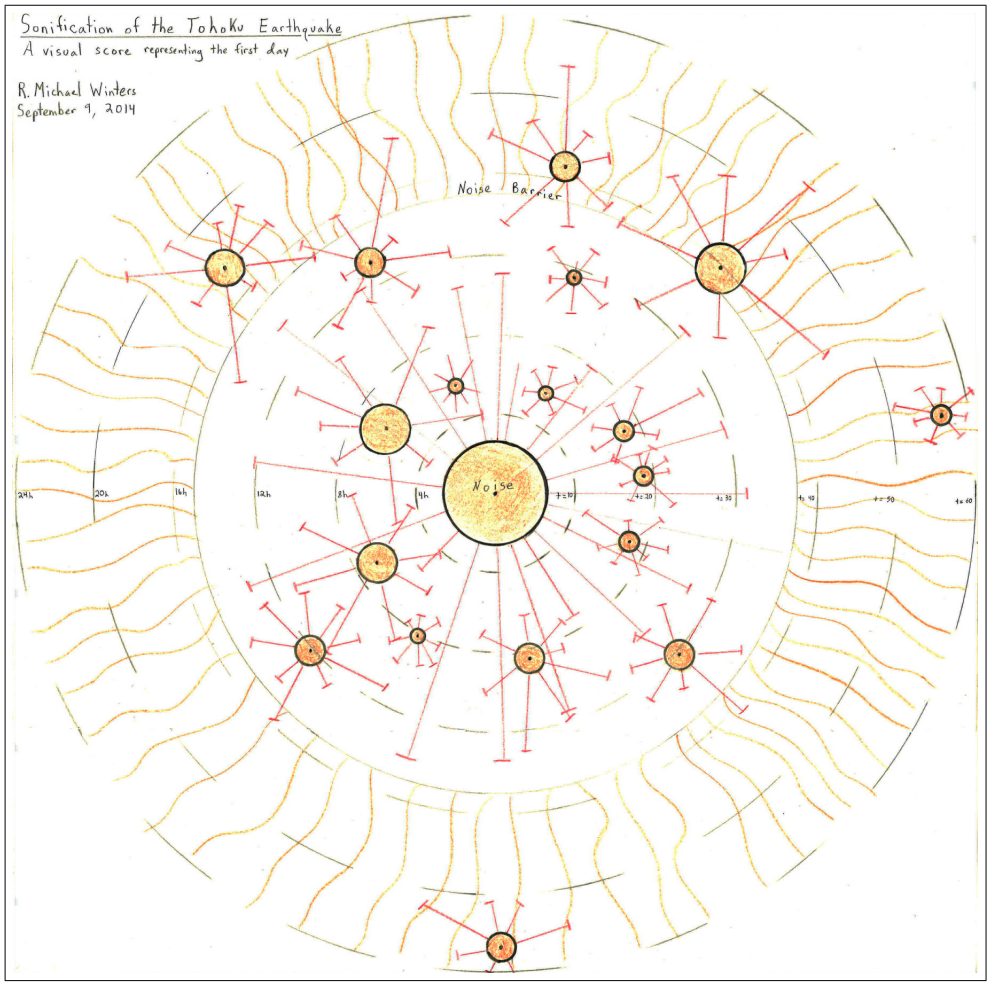


Figure 1: A visual score representing one minute of the *Sonification of the Tohoku Earthquake*. Time radiates outwards from the center of the canvas. The primary, central circle represents the first earthquake, and the additional circles are salient aftershocks with foci representing their exact moment in time. The loudness of each aftershock is represented by the radius of the circle.

and the circle's circumference. The purpose of this choice was to draw attention to the similarity of the aftershocks to the initial quake. Although not as loud, they arise as essentially less intense versions of the first event. Although there is not a similar peaceful noise that immediately precedes them, their seemingly random occurrence in time draws attention to the fact that the moments immediately preceding them could be thought of as a relative stasis.

### 4.3. Video

*Tohoku* was released as a video with the audification time-aligned with the recorded seismometer data. For many listeners, this visual component (or score) will figure highly in their cognitive representation of the piece. A few characteristics of the video should be highlighted. For one, there is a vertical tracker that moves with respect to time, indicating the precise position that is being heard at each moment. This assists in the auditory presentation, alerting the viewers to the place in the signal that is currently producing sound, and leading their attention to events that will occur in the future. When these events do occur, the listener can expect it and perhaps better focus their attention to the bimodal correspondence of the two mediums.

This dynamic audio visualization is coupled with a small map placed in the lower right hand corner of the screen. The map visualizes the magnitude of each aftershock and couples it to the station in Japan or Russia where it was recorded. Thus, when an aftershock is heard, it can also be "placed" in terms of its geo-physical location. This small map adds content that the pure audification could not, a reference point to a specific place.

## 5. ANALYSIS

Having presented the context and content of *Tohoku*, this section analyzes it with respect to questions that were identified in the in-

troduction:

1. What features contribute to *Tohoku's* popularity?
2. What about *Tohoku* offers experiences of the sublime?
3. Is *Tohoku* a "success" for the sonification community?

### 5.1. Popularity

In line with Supper's study of "the public fascination" of sonification [19, Chp. 2], the popularity of Tohoku can be at least partially attributed to the rise of three types of digital technology: digital images, digital audio, and digital publications. In this case, the digital image is a video that superimposes text, a time-aligned seismograph, and a heat map. These features further the composition by reinforcing clarity in the acoustic content, even allowing the viewer to direct their listening to events before they happen. Although original "audifications" of seismographs would involve magnetic tape [10] (thus being analog), *Tohoku* benefits from technologies related to digital audio. For example, by using digital audio, the creators were not limited in their playback speeds, and selected a speed that was 1440 times the original recording speed, allowing the simple conceptual transformation of 1 day $\leftrightarrow$ 1 minute. As a YouTube video, the creators also benefited from the ease of digital publication. YouTube provided a media for rapidly transmitting audio and visual content across the web without an intermediary. No publicist advertised "this is what an earthquake would sound like if you were a giant buried in the earth"—this was an unsolicited comment contributed by a member of the listening public.

The second aspect of *Tohoku* that contributed to its popularity is its clarity and intelligibility. As discussed in Section 3, *Tohoku* is marked by compositional simplicity created by direct translation of the data into an audio signal (i.e. audification). The creators could have chosen to represent the same data using traditional musical instruments or an advanced sound generation system, but they did not. The result is a sound and formal structure that does not circumvent listener expectations: earthquakes are loud, noisy, explosive events that are unpleasant and shocking. There would be no reason to expect an earthquake to have a rich harmonic spectrum, or lead to a musical piece that is repetitive or pleasant sounding. Combined with the time-aligned video, there are no "sounds" that occur without a visual counterpart. Instead, "hidden content" in the visual signal is revealed through a roaring, deep timbre with occasional pops with higher spectral centroid. For any listeners that did not listen all the way through, the first few seconds would have communicated the authenticity of its timbre sufficiently.

Lastly, the popularity of *Tohoku* can be linked with a well-understood physical event with large social impact. Apart from the catastrophic consequences to infrastructure, environment, and lives, the event was greeted with several days of international media coverage extending well beyond Japan's physical borders. It is not often the case that a "scientific" sonification would target data sources concomitant to a specific geo-social event, much less hastily publish to a broad audience nine days after the catastrophe first struck. This role might be attributed to an artist or social commentator, whose interest may be social and cultural rather than scientific in nature.

### 5.2. Auditory Sublime

A stated goal of this paper is to make explicit the "sublime listening experiences" theory of sonification popularization [7], and apply it to actual listening experiences as opposed to the offerings of publicists. This theory has been demonstrated in the various scientific fields traditionally associated with the sublime (e.g. the large and powerful), but also to fields of the small and subtle. Engendering a sublime emotion requires two basic elements and one secondary. In the first, phenomenon are required that inspire notions of the sublime through their own unique characteristics. In the second, sound is applied to communicate the associated phenomenon, creating a new experience that is immersive and visceral, and for which visuals alone are pallid or insufficient. With this concoction brewed, the applied technical facilities of digital audio, images, and publication contribute to its diffusion, reproduction, and reception.

Several features of *Tohoku* make it a good candidate for the auditory sublime. Firstly, and most directly, its subject matter (an earthquake), appeals to tried and true conceptions of the sublime. The earth—large and great—is wretched into peril through sudden, overwhelmingly powerful tremors affecting everything on its surface. The power of these quakes and their after-effects demonstrate that even the most robust and sophisticated of human engineering endeavors are essentially feeble. The greatness and power of this phenomenon creates terror in unmediated experience, but for those whose experience is mediated, the estimation of its power and greatness in relation to the self triggers a sublime emotion.

The audification approach chosen by the creators astutely carries forth these features in an acoustic signal. Power and magnitude are brought forth in the loudness and noisiness of the sound, which under the right listening circumstances can cause an immediate "fight or flight" response due to the emotional mechanism of "brain-stem reflex" [27]. The creators go so far as to warn their listeners of an impending "loud signal," presumably to temper or avoid this automatic averse reaction. Within all acoustic qualities that might communicate power and greatness, overwhelming loudness would appear to be most adept. The noisy, low timbre and subtle spatialization in no doubt contribute, but if so, more likely to the immersive and visceral environment. Coincidentally, loudness figures in original writings of the sublime. The philosopher Edmund Burke recalls in his *Philosophical Enquiry*, "excessive loudness alone is sufficient to overpower the soul, to suspend its action, and fill it with terror" [15] (as quoted by Kahn [13]).

Although acoustic features of *Tohoku* might trigger terror, magnitude and power are not in and of themselves qualifiers for a sublime reflection. Experience must be mediated—the subject must identify themselves as separate from the phenomenon, be reprieved of terror and anguish, and ultimately realize that they are conceiving something almost inconceivably great and powerful. In his formal treatment of the sublime, Kant summarizes this additional content as preparatory knowledge, culture, and mediation [16]. Though the object of sublime reflection is worthy of terror, the sublime is only elicited upon more thoughtful consideration. The object may be inconceivably large and powerful, but realizing that one is experiencing this grandeur elevates consciousness above fear and into the recognition of its own part in sublimity.

Thus, when considering the degree to which *Tohoku* might create a sublime listening experience, it is necessary to recognize that the listener must be equipped with an understanding of the deeper meaning of what is being heard. When listening, their consciousness and knowledge must have adequate preparation to the point that the audible instantiation is simply an acoustic anchor to the physical embodiment. This preparation may be provided by advertisers that "teach" the public how to listen [21], but may also arise

without grandiose titles or fanciful appellations from the sonic vernacular. In any case, a sublime listening experience is brought forth by sonic qualities that contribute to terror, immersion and viceralness, but can not be solely derived from the acoustic signal.

### 5.3. Success

Continuing with a discussion that began in Section 2, the popularity of a sonification does not necessarily make it "successful" for the community. By eliciting listening practices rooted in social relations and culture, popular sonifications may do little to further its acceptance as a scientific method [28]. When a creator or advertiser appeals to musical metaphors and formal structures, listeners might enjoy a sonification aesthetically and be only marginally aware of the data relationships it purports to objectively represent.

From this perspective, a popular sonification might become successful in so far as it *transgresses* traditional social and cultural functions of listening and seeing. Although seeing is the dominant mode of scientific and functional analysis, a successful sonification demonstrates the deficiencies of visual-only techniques, revealing unseen information that is too fast, subtle, or otherwise insufficient for visual representation. Outside of the senses of science, the writer Jonathan Sterne refers to this problem as "the audiovisual litany" [21]—-listening and hearing are not merely vehicles for mystical [29], emotional [30], or subjective [31] experience.

For *Tohoku*, popularity is relative. Although having over fourty-seven thousand views to date on YouTube, this hardly would qualify for popularity compared to scores of videos available on the same media platform. With respect to sonifications, other examples surpass it quantitatively, but either evade the term "sonification," use traditional, subjectively-oriented sonic vocabularies (e.g. calling it "music"), or have significant content that is not the sonification itself. Lastly, other examples may have had more "listens," but have either not been published online, or have used dissemination strategies that do not divulge play counts. With these limitations made clear, as a public facing example, *Tohoku* may be the most popular sonification on the web.

Sidestepping missed opportunities through a hearty "Sonification" title, the success of *Tohoku* may be still be equivocal given the factors previously described. As a video, the present discussion examines the balance of audiovisual materials, specifically the degree to which the sonification complements or augments the visuals with content that is unseen. The complementary function of sound is brought forth though a time-aligned seismograph and time-cursor—much like a digital audio workstation (DAW). As with DAWs, the impression this visual display imparts onto the viewer is that the sound is derived directly from "the data." In this case, because the sonification is actually an audification, this interpretation closest to being technical correct. This direct correspondence further emphasizes that visuals and audio are in some respect interchangeable mediums. The data is a "recording" of the sound, and the sound is a "playback" of the data. As in DAWs, the fact of equivalence of visuals and audio is surpassed by the fact that the visuals do not display the actual content, but are in fact a reduction. Only through playback does the data make itself truly available to the listener. The content that is hidden in the visual reduction encompasses all the colors of qualities of audio recordings. Thus, *Tohoku* clearly supports at least one cornerstone argument for sonification—sound can convey information than can be seen [32].

## 6. BROADER DISCUSSION: "MUSIC"

In this paper, it has been argued that the popularity of *Tohoku* can be attributed to the digital technologies involved in its dissemination, its clarity and intelligibility, and its rich conceptual and sociocultural meaning. Although *Tohoku* had several characteristics that made "sublime listening experiences" possible, actually having this experience was found to be dependent upon listeners having the requisite preparatory knowledge and culture. Although *Tohoku* might hold subjective and affective appeal, it presents sound as a complementary and interchangeable medium to visualization that can provide more information than available visually.

In the present paper, a "musical analysis" was applied to a sonification, providing a thoughtful framework for the presentation of content, and supporting a discussion relating to popularization, the auditory sublime, and success. Specifically, a "score" was appropriated to facilitate audio content analysis. Historically, the relationship of sonification and music has been troubled. The term "sonification" is too often appropriated to describe creative processes that only loosely fit the bill. Meanwhile, the popularity of these examples does little to further the public acceptance of listening as a useful, objective or scientific method. Drawing the public to sonification using metaphors drawn from the sonic vernacular (e.g. "music") also can not be condoned.

However, it is not the case that music and sonification must remain forcibly distinct. Music offers frameworks, tools and results that equip the field of sonification for complex tasks, and indicate areas where visuals alone will pale [33]. Music research is also a source of data in and of itself for which sonification can be applied and benefit from the shared medium and listening culture supported therein [34, 35]. Analysis such as the present demonstrate future areas for crossover work, specifically how music can assist in the analysis of non-specialist listening experiences. More generally, *Tohoku* is exemplary of a "mutually beneficial" relationship between scientific and artistic fields [5].

The listening aesthetic and processes involved in audification, and perhaps auditory seismology more specifically are not isolated, and can be linked with several recent trends in music composition and technology [36]. *Tohoku* is an example of listening to our natural acoustic environment in new ways, and of focusing our auditory attention to phenomenon that might previously go unheard. It therefore demonstrates clear links with similar goals arising in acoustic ecology and soundscape composition [26, 37]. Because of the naturally indeterminate structure of earthquakes, and the relative absence of mapping decisions that characterize audification, *Tohoku* can be considered as an advanced form of aleatoric composition. The composers have narrowed their composition to a specific event, a timeframe, and a spatialization, but have let all other matters of the composition unfold naturally as they would by chance. Lastly, the appropriation of technologies to make sound, perhaps even those that previously did not make sound (like a seismometer), is rooted in a tradition that developed through pioneering work by Christian Marclay and others in the 1970s. Although their works were grounded in sound-producing technologies, the appropriation of a non-sound producing technology for sound production is a clear extension.

However, *Tohoku* was not created for a concert hall or performance. It does not come with a score or a composer, and most likely this piece was not created with musical listening in mind. *Tohoku* is unequivocally a sonification. Even more, it is a type of sonification that treats the acoustic translation of data in a most

direct, pure way. Pieces such as these draw attention to listening modes in sonification [4] that can capture the listening attentions of a broad audience. *Tohoku's* scientific and creative roots speak clearly to the noted capacity of sonification to transcend discipline [3], and further to the ability of sonification to be listened to musically [2]. Perhaps future considerations rooted in music might contribute to a more prevalent place for sonification in culture and society.

## 7. DESIGN GUIDELINES FOR SOUND OUTREACH

This paper has presented an in-depth analysis of one popular example of sonification. There are many others, and certainly more to come. Popularization can be beneficial to the research community due to the exposure that these examples can provide, but too often poor choices are made that stymie or even counteract positive outreach. As this paper has argued, a public-facing sonification is "good" insofar as it is capable of advancing the theory of sonification in its listeners. This requirement does not forbid an affective and aesthetic reaction of its listeners. However, this can not be the only understanding imparted.

The goal of this section is to provide data-independent guidelines for creating public-facing examples of sonification that are ethically sound. These guidelines should contribute to publicity without detracting from scientific legitimacy.

1. Pair sonifications with visualizations
2. Publish on websites that allow re-sharing
3. Use mappings "authentic" to the data source
4. Balance word choice to preserve scientific character

For sighted individuals, the use of visuals to aid in the presentation of a sonification is crucial for two reasons. Firstly, for aesthetic reasons, an image or video can give the listener's visual attention and memory something to latch on to—standing as a visual anchor for the sound. Visuals can inspire imagination and also educate on what is being heard. As in the present case, visuals can also advance the theory of sonification by demonstrating how sound can provide more information than visuals alone.

The choice of medium for publication is also important. Sonifications should be published on sites that allow for re-publication (e.g. "sharing"). If the sonification is paired with a dynamic visualization or video, a good choice for sharing would be YouTube. If the sound is paired with a static visual or picture, a good choice would be SoundCloud. In both cases, the ability for users to share will assist with dissemination and finding new listeners. From these points, a poorer choice for publication would be in an HTML5 Audio tag. Alone, this tag does not allow for republication, and furthermore does not include an image.

With regards to sound design, an illusion of "non-mediation" may be helpful in establishing the authenticity of the mapping. Certain data types admittedly do not have associated sounds (e.g. Twitter), yet the sound designer should make an effort to provide sounds that have a clear correspondence to the data. It would be best if is not obvious that there is any "mapping" at all. The sound should be authentic—like a simple photograph. "The Singing Comet" mentioned previously provides such a mapping. Although the authors have not yet divulged their mapping strategy, the sound has a certain "audification" quality, which allows the audience to listen as though they were listening to a true recording. It therefore seemed *authentic* to the data source. Although a sonification designer might be tempted to weave a musical tapestry for their own enjoyment or to increase "pleasantness" of the data, this is inadvisable for public consumption. If there is not a clear link between the data and the sound, the fact that sonification is objective, reproducible or functional—even to the point of surpassing visualization—will be lost.

The last point that should be highlighted is with regards to word choice or "framing" of the sonification. Dissemination strategies designed to highlight the "musical" character of an example are particularly questionable. Although a sonification can be listened to musically and trigger profound experiences in a listener, if the title or description of the work does not include the word "sonification" or the fact that there is any objective function to listening, it can not contribute to advancing the field in the public sphere.

## 8. CONCLUSION

*Tohoku* is a success for the sonification community. In the past four years, it has garnered over forty-seven thousand views, making it one of the most popular sonification-titled examples on the web. The source of this asset is its ability to engage listeners of many backgrounds, mostly non-specialists, and present them with sounds they had never before heard, realities they had never before experienced. Its capacity for translation is two-fold. Beyond its basic translation—that of inaudible to audible—it also provides an easy-to-understand example of sonification to a community that may previously been unaware of its existence.

Although this paper demonstrated how popularization may sometimes detract from sonification's scientific mission, *Tohoku* demonstrates how sound can display more information than available visibly—a key argument in the theory of sonification. Several factors contributed to its popularity: digital images, audio and publication, the mapping's clarity and intelligibility, and being tied to a well-known socio-cultural event. *Tohoku* involves data traditionally associated with the sublime, and the aesthetic choices made my the creators (i.e. audification) contribute to the terror, immersion and viceralness of the piece. Actually having a "sublime" listening experience was found to be dependent upon the preperatory culture and knowledge of the listener, which may be cultivated by an advertiser, but can arise independently in the listener themselves.

Although the advertisement of "sublime listening experiences" may in some cases detract from the pursuit of scientific legitimacy, the two are not incompatible. The framing and word choice of advertisers can do more to stymie the success of a popularization. Not mentioning the word "sonification," or drawing upon traditional associations of sound as a subjective, mystical, or aesthetic medium make for missed opportunities to advance the theory of sonification in the public's eye. Non-specialist listening does not require compromising clarity, intelligibility and objectivity of a sonification. Instead, they should be employed to support the full biological, cognitive, social and cultural capital of sound.

## 9. REFERENCES

[1] T. Hermann, "Taxonomy and definitions for sonification and auditory display," in *Proceedings of the 14th International Conference on Auditory Display*, Paris, France, June 2008.

[2] P. Vickers and B. Hogg, "Sonification abstraite/sonification

concrète: An 'aesthetic perspective space' for classifying auditory diplays in the ars musica domain," in *Proceedings of the 12th International Conference on Auditory Display*, London, UK, June 2006.

[3] F. Grond and T. Hermann, "Aesthetic strategies in sonification," *AI & Society*, vol. 27, no. 2, pp. 213–22, 2012.

[4] ——, "Interactive sonification for data exploration: How listening modes and display piurposes define design guidelines," *Organised Sound*, vol. 19, no. 1, pp. 41–51, 2014.

[5] R. M. Winters, "Exploring music through sound: Sonification of emotion, gesture, and corpora," Master's thesis, McGill University, Montréal, Canada, August 2013.

[6] A. Supper, "The search for the "killer application": Drawing the boundaries around the sonification of scientific data," in *The Oxford Handbook of Sound Studies*, T. Pinch and K. Bijsterveld, Eds. New York, NY: Oxford University Press, 2012, ch. 10, pp. 249–70.

[7] ——, "Sublime frequencies: The construction of sublime listening experiences in the sonification of scientific data," *Social Studies of Science*, vol. 44, no. 1, pp. 34–58, 2014.

[8] P. Vickers, "Sonification and music, music and sonification," 2015, submitted.

[9] C. Davison, "Earthquake sounds," *Bulletin of the Seismological Society of America*, vol. 28, no. 3, pp. 147–61, 1938.

[10] S. D. Speeth, "Seismometer sounds," *Journal of the Acoustical Society of America*, vol. 33, no. 7, pp. 909–16, 1961.

[11] C. Hayward, "Listening to the earth sing," in *Auditory Display: Sonification, Audification, and Auditory Interfaces*, G. Kramer, Ed. Reading, MA: Addison-Wesley, 1994, pp. 369–405.

[12] F. Dombois, "Using audification in planetary seismology," in *Proceedings of the 6th International Conference on Auditory Display*, Espoo, Finland, July 2001.

[13] D. Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts*. Berkeley, CA: University of California Press, 2013, ch. 11, pp. 133–61.

[14] J. Muir, *Our National Parks*. Boston, MA: The Riverside Press, 1901.

[15] E. Burke, *A Philosophical Enquiry into the Origin of Our Ideas of the Sublime and Beautiful*. New York, NY: Oxford University Press, 2008.

[16] I. Kant, *Critique of Judgement*, J. C. Meredith, Ed. New York, NY: Oxford University Press, 1957.

[17] A. Supper, "'Trained Ears' and 'Correlation Coefficients': A social science perspective on sonification," in *Proceedings of the 18th International Conference on Auditory Display*, Atlanta, Georgia, 2012.

[18] R. Jütte, *A History of the Senses: From Antiquity to Cyberspace*. Malden, MA: Polity Press, 2005.

[19] A. Supper, "Lobbying for the ear: The public fascination with and academic legitimacy of the sonification of scientific data," Ph.D. dissertation, Maastricht University, Maastricht, Netherlands, 2012.

[20] P. Bordieu, *Outline of a Theory of Practice*. New York, NY: Cambridge University Press, 1977.

[21] J. Sterne, *The Audible Past: Cultural Origins of Sound Reproduction*. Durham, NC: Duke University Press, 2003.

[22] F. Dombois and G. Eckel, "Audification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Berlin, Germany: Logos Verlag, 2011, ch. 12, pp. 301–24.

[23] G. Kramer, Ed., *Auditory Display: Sonification, Audification, and Auditory Interfaces*. Reading, MA: Addison Wesley, 1994.

[24] J. L. Flanagan and R. M. Golden, "Phase vocoder," *Bell System Technical Journal*, vol. 45, pp. 1493–509, 1966.

[25] F. Grond and J. Berger, "Parameter mapping sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Berlin, Germany: Logos Verlag, 2011, ch. 15, pp. 363–97.

[26] H. Westerkamp, "Linking soundscape composition and acoustic ecology," *Organised Sound*, vol. 7, no. 1, pp. 51–6, 2002.

[27] P. N. Juslin and D. Västfjäll, "Emotional responses to music: The need to consider underlying mechanisms," *Behavioral and Brain Sciences*, vol. 31, no. 5, pp. 559–621, 2008.

[28] G. Kramer, B. Walker, T. Bonebright, P. Cook, J. Flowers, N. Miner, J. Neuhoff, R. Bargar, S. Barrass, J. Berger, G. Evreinov, W. T. Fitch, M. Gröhn, S. Handel, H. Kaper, H. Levkowitz, S. Lodha, B. Shinn-Cunningham, M. Simoni, and S. Tipei, *The Sonification Report: Status of the Field and Research Agenda*. Santa Fe, NM: International Community for Auditory Display (ICAD), 1999.

[29] K. Wolfe, "Sonification and the mysticism of negation," *Organised Sound*, vol. 19, no. 1, pp. 304–9, 2014.

[30] R. M. Winters and M. M. Wanderley, "Sonification of emotion: Strategies and results from the intersection with music," *Organised Sound*, vol. 19, no. 1, pp. 60–9, 2014.

[31] M. Chion, *Guide des Objets Sonores: Pierre Schaeffer et La Recherche Musicale*, J. Dack and C. North, Eds. Paris, France: Institut National De L'Audiovisuel & Éditions Buchet/Chastel, 1983.

[32] B. N. Walker and M. A. Nees, "Theory of sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds. Berlin, Germany: Logos Verlag, 2011, ch. 1, pp. 9–39.

[33] R. M. Winters and M. M. Wanderley, "Sonification of emotion: Strategies for continuous auditory display of arousal and valence," in *Proceedings of the 3rd International Conference on Music and Emotion*, Jyväskylä, Finland, June 2013.

[34] R. M. Winters, A. Savard, V. Verfaille, and M. M. Wanderley, "A sonification tool for the analysis of large databases of expressive gesture," *International Journal of Multimedia and Its Applications*, vol. 4, no. 6, pp. 13–26, 2012.

[35] R. M. Winters and J. E. Cumming, "Sonification symbolic music in the ELVIS project," in *Proceedings of the 20th International Conference on Auditory Display*, New York, NY, June 2014.

[36] V. Straebel, "The sonification metaphor in instrumental music and sonification's romantic implications," in *Proceedings of the 16th International Conference on Auditory Display*, Washington, D.C., June 2010.

[37] A. Polli, "Soundscape, sonification, and sound activism," *AI & Society*, vol. 27, pp. 257–68, 2012.