# Adaptation of Listener Respiration to Heard Music

## Topic Proposal for PhD in Music Technology

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October 21, 2013

## Topic

Respiration has an obvious role in many kinds of music making, but the question of how we breathe when listening to music is relatively new to empirical investigation. There has been a sustained focus on how often or how deeply listeners may breathe, as a indication of arousal and emotion, but recent studies suggest this approach may be compromised by a competing effect of music on listeners inhalations and exhalations. Measurement of respiratory behaviour during repeated listenings to the same music shows alignment of when a listener breathes to the music, both in experienced musicians, e.g. (Upham, 2013), and non-musicians (Sato et al., 2012). Other studies show periodic regularity close to musical meter in respiratory rate of some listeners, to some stimuli (Haas et al., 1986; Etzel et al., 2006). If music encourages listeners to breath at particular rates (respiratory period adaptation) or inhale at particular times (respiratory phase adaptation), this would interfere with interferences from respiration data. For example the assessment of arousal via respiration rate might be compromised as the cause for change in rate would be due to the stimulus cues rather than the listeners' emotional state. However, it is also likely that the effect of music on how listeners' breath, or specifically when they breath, is relatively light, as we would surely notice if the entire audience breathed together, as dictated by the performers or whatever played on the radio.

In order to investigate when, how, in whom, and why respiratory adaptation takes place during music listening, we need a means of assessing it. I propose studying how listeners respiratory cycle adapt to musical stimuli, using numerical models of respiration to track adjustments of subjects respiratory period and evaluate phase alignment with expected phase according to empirical data from other listenings or hypothesized models of the music. Experimental data already collected and more from planned experiments will form the empirical basis of modelling respiratory phase adaptation and alignment with musical works.

## Need for study

Respiration is a very important part of how we communicate. Besides its obvious role in making speech sounds, humans are generally sensitive to how much air is in the speaker's lungs (Milstein &

Watson, 2004), using this information to navigate joint actions such as dialogue (McFarland, 2001). How some one is breathing tells us about how hard they are working physically, whether they are relaxed or anxious (Pellegrini & Ciceri, 2012), listening or eager to speak. Respiration cues are routinely used to coordinate time sensitive activities (Standal & Engelsrud, 2013), prominent in solo and team sports, ensemble music making, and even in common activities like carrying heavy and delicate objects together (Pellegrini & Ciceri, 2012).

Listeners respiratory behaviour show entrainment like behaviour, however the resultant alignment does not necessarily manifest like the more commonly studied phenomenon of metrically entrained movement. Evaluating respiration behaviour over repeated listenings to the same musical stimuli shows that some moments in the music engage very consistent respiratory behaviour, while other moments are less controlled (Upham, 2013). Also, some music encourages specific respiration patterns, while others have little effect. In contrast, metrical entrainment is very stable and persistent. This variability in respiratory behaviour is surely part of the compromise between the metabolic gas exchange requirements of the listener and the strength of cues in the music, but the details are as of yet a mystery.

Respiration of a given listener might be similar from one listening to the next, it is not strictly identical, listeners response may be variable with attitude or mood. It may be that respiration entrainment is dependent on the listeners' engagement with the music, attention to the auditory stimulus, and sympathy for the emotion expressed in the piece. And as of yet, we do not know if one listener's consistencies are the same as another's, it may be that life time characteristics like personality and musical experience determine how sensitive a listener is to the respiratory suggestion.

Why might music encourage particular respiratory behaviour in listeners, at least some of the time? There are several plausible hypotheses:

1. Metrical Regularity: a listener's periodic respiratory cycle naturally, gradually adjusts to fit to another periodic system, the meter or hypermeter of the heard music.

2. Respiratory metaphor in musical temporal sequence: If we use a respiratory metaphor to make

sense of the temporal character (articulation, sustain) or organisation (melodic phrase and segmentation), the evoked model may influence the behaviour of our own bodies. Moments of variable tempo may be another type of musical event which may rest on respiratory metaphors.

3. Performer mimicry: Instead of interpreting the music with breath, we may infer the respiratory behaviour of the musicians making the sound, whether their respiratory system in part of the sound generation process or auxiliary, and potentially related to structure or interpretation.

4. Action coordination: In other domains, we coordinate our temporal experience and action by aligning our respiration with others (e.g. coordinated lifting) or in alternation (e.g. dialogue). Respiration of listeners may reflect an active engagement with the presented music, covert or imagined.

5. Masking avoidance: As our own respiration makes noise and can mask sounds in the environment, listeners may use temporal expectations to breathe strategically to avoid hiding interesting or important information in the musical signal.

The clues to which hypotheses are important lies in how the respiratory cycle of listeners become aligned to the music. What cues encourage particular patterns of breathing, and what kinds of music, what contexts of listening,which types of listener and which listener attitudes facilitate this placement of breath? With a means of assessing the adaptation of a listener's respiratory sequence (the time course of inhalations and exhalations) to the music, we can explore these issues in turn.

## Related Literature: Respiration, music, and synchrony

Most work looking at listener respiration during music listening has been focused on relating change in respiratory behaviour to emotional responses to music, as a measure of experience. Many studies have related respiratory rate, depth, inhalation/exhalation time ratio, and carbon dioxide expulsion with music of higher or lower arousal levels (Iwanaga & Moroki, 1999)(Krumhansl, 1997) (Bernardi et al., 2006). Another tact is to look at heart rate variability (Kleiger et al., 2005), a phenomenon related to respiratory sinus arrhythmia, a consequence of the respiratory cycle on heart rate (Yasuma & Hayano, 2004)(Barbi et al., 2006). Measurable in most adults under particular circumstances like meditation, intense focus, or relaxation, or in particular people, like children or elite athletes(Bjurstrom & Schoene, 1987), respiratory sinus arrhythmia is a regular modulation of heart rate with respiratory phase (with inhalation, the heart beats faster, with exhalation, it slows down), this phenomenon is considered a curious and desirable state, presumed to be a sign of efficient use of oxygen and health (Schäfer et al., 1998). When RSA is pronounced, the variability of heart rate is much higher. There is much disagreement as to what this phenomenon indicates, however it has been shown that HRV can be influenced by musical stimuli, and RSA has been found in remarkable circumstances of music production as well (Müller & Lindenberger, 2011)(Vickhoff et al., 2013)(Iwanaga et al., 2005)(Kleiger et al., 2005). There is some criticism of using these measures of engagement or emotional response to stimuli which interact directly with respiration (Buchner, 2011; Beda et al., 2007; Naruse & Hirai, 2000; Stark et al., 2000).

It is necessary to explore the reasons behind the way listeners respiration sequences adapt to a musical stimulus before considering the systems effected down the line.This lit review is organised by hypotheses of respiratory adaptation outlined in the previous section.

## Hypothesis 1: Metrical entrainment

A few studies over the years have stumbled upon what appears to be examples of listeners breathing in integer ratio periods to the meter of heard music. Hass et al. found some participants breathing metrically for some stimuli, and noted that most of those who did were musically trained 1986. More recently, cross correlating the respiration sequence (captured by a stretch sensor around the chest) with a smoothed envelope of the sound wave suggested a metrical regularity to several subjects respiration, again with a prominence of consistency from musicians (Etzel et al., 2006).

However, the alignment of respiratory cycle with meter is not strictly fixed, it shifts somewhat with respect to the stimulus, suggesting the phase locking is not constant(Yamamoto & Miyake, 1999). Initially analysis of repeated listenings show moments on consistent respiration are fleeting, even when significant (Upham, 2013). Likely other aspect of music are encouraging these instances of consistent respiratory phase.

### Hypothesis 2: Respiratory metaphore in music structure

Melodic phrase has been indirectly related to respiration through speech metaphores since at least classical times (Mathiesen, 1985), arrising again in discussions of rhetoric and good melodic formation of the 18th c. with metaphors of punctuation (Honan, 1960)emphasising structure and pause in the formation of a good line.(London, 1990)(Cohen, 2002) . Indeed the predictability of respiratory behaviour during speech and poetry reading is well documented(Conrad et al., 1983; Cysarz et al., 2004; Winkworth et al., 1994), making it an apt link for the interpretation of parallel musical processes of proclamation (Ranum, 2001). Other components of musical structure have also been hypothesised to relate in abstract and in practice with respiration, such as harmonic rhythm(Swain, 1998) or articulation, and tempo variation (Upham, 2013). For many of these structural components, it would be reasonable to suppose that the respiration of the performer would be aligned with these elements, if they were useful in defining the music.

### Hypothesis 3: Mimicry of the performer

Depending on what is being performed, respiration and music can be tightly coupled via sound generation (singing and wind instrument playing), or related through ancillary gestures (piano, strings), or nearly irrelevant (DJ'ing, presumably). Studies of choral music predictably find that performers breath together, more surprisingly yielding shared patterns of heart rate variability as well (Müller & Lindenberger, 2011)(Vickhoff et al., 2013). An analysis of cellists and their respiratory sequence considered many possible factors, from phrase boundaries, to dynamics, to meter, to bowing, yielding interesting predictive rules for when and how a player would breathe in performance of different pieces (Igarashi et al., 2002). A study of pianists found less consistency, perhaps because pieces performed and the mechanics of performing polyphonic textures. Respiration rate was fairly reliable but phase alignment was often quite different between successive playings of the same works (King & Ginsborg, 2011). In performance, listeners can integrate visual cues for estimating the respiratory state of the musicians, and in recordings, there are often audible inhalations along side other signs of ventilation. It would not be hard, in many circumstances, to guess when the performer will breath again, if that were interesting information for the listener. Indeed, breathing with others improves listeners evaluation of the effort needed and nature of a task (Pellegrini & Ciceri, 2012), and the effort, or at least apparent effort, is salient in most forms of performance. Even without deliberate breath matching, such a model might come to influence their own breathing, synchrony by proximity. But practically, listeners often can't breath exactly like performers; they would hyperventilate unless they had comparable uses for the air. More likely is the possibility that listeners sometimes breath with performers, when its particularly relevant.

## Hypothesis 4: Respiration in joint activity and temporal control

Intermittent respiratory phase alignment is often used for coordination in a multitude of cooperative activities. Chamber music ensembles often coordinate with breath, e.g. string quartets (Seddon & Biasutti, 2009), particularly in music with variable tempo (romantic) (is this true). In a more day-to-day example, researchers found that pairs of participants charged with carrying a delicate, heavy and awkward object through an obstacle course has more instances of coordinated breathing than when at rest (Pellegrini & Ciceri, 2012). Sometimes coordinated respiratory behaviour is not for the purpose of reflecting what is presented by another, but to compliment in the context of joint-action (Watanabe & Okubo, 1997; Rochet-Capellan et al., 2012; McFarland, 2001). While a listener, particularly a music listener stuck in a lab under measure, is not usually very active, there is evidence imagined action and thought modulating respiratory behaviour (Moran et al., 2012; Chapell, 1994). An interesting study in which participants performed tasks aloud, subvocally, and quietly (without articulation, i.e. imagined action) there were marked differences in inhalation/exhalation ratios between the imagined tasks of spontaneous speech and problem solving and those of reading and reciting familiar word sequences (Conrad & Schönle, 1979), namely the latter was much closer to relaxed vegetative breathing, while the former was more like actual speech. Even when not conceptualised as alignment to actions of others, respiration is also an important mechanism for many temporally controlled actions, such as sport and dance (Standal & Engelsrud, 2013; Hanrahan & Vergeer, 2001). Regular locomotion synchronous breathing is often associate with more efficient action, depending on the circumstance, as is listening to music. If respiratory consistency reflects imagined action on the part of the listener, this would depend on how practiced that listener might be at musically coordinated actions (and mental rehearsal), on what the listener was imagining, to what degree of vividness, and concentration. Also, such alignment might be fleeting, and variable (improvised) rather than rote or fixed.

### Hypothesis 5: Avoidance of masking

The last hypothesis must be considered, though it hardly follows from the previous possibilities. Breathing comes at a cost, in particular, breathing in and out makes noise. while we are practiced at ignoring these noises, there are often times when it would still overwhelm sounds we are anticipating hearing form the environment. This masking issue is one explanation for why we hold our breath when waiting for something to happen any moment now. (Stekelenburg & Boxtel, 2001) It could be that listeners may simply be controlling when the breath to avoid covering musical sounds they are expecting to hear at certain moments. It is not clear if a breath between phrases would be mimicry of the performer or masking avoidance, but other instances might arise as useful clues as to the relevance of this phenomenon when listening to music and breathing.

## Methods

The empirical work for this thesis will fall into two parts: develloping a method to assess respiratory period and phase adaptation, and manipulating potential factors for respiratory alignment. Investigation in the way respiration adapts in response to a musical stimulus depends on have a way to measure when a listeners breath adjusts to align with the music, and how well that alignment is sustained.

Respiration, or more specifically ventilation, is an oscillatory physiological behaviour which has been studied and modelled mathematically from many angles. Non-linear dynamics and applied mathematics has been interested for years in the interaction of periodic systems, including many kind of physiological phenomena (Glass & Mackey, 1988). This modelling may employ more general models (Glass, 2001), or respiration specific models. Though many existing model prioritize specific aspects of respiratory behaviours which are not relevant to the issue of phase alignment with an external stimulus (Batzel, 2007), some may should interesting parallel. The interaction of locomotion and respiration (Daffertshofer et al., 2004), mechanical ventilation and patient respiration (Phillips, 2007), or studies of adaptative motion in joint action such as speech (Raab et al., 2006; McFarland, 2001; Bailly et al., 2013) may be sufficiently similar to launch models of the interaction of music and listener respiration.

The first step is to derive a model of how music influences respiratory oscillations, whether as intermittent phase perturbing cues or a continuous ideal respiration sequence to which listener's breath might align. Working with respiratory sequences from repeated listenings to the same music from a given listener, for example the solo response project data, music effect models can be evaluated. With a mode of the musics influence, it is then a question of evaluating whether and when a listener's respiration during a single listening 1) adapts to the sequence encouraged by the music and 2) sustains alignment.

With a sufficiently developed analytic frame work, new experimental data can then be collected test the different hypotheses of how music is influencing when listeners breathe. The experiments will employ the repeated listening paradigm, working with a few participants and recording their responses while they listen to the same musical stimuli many times. Potential factors to manipulate may be:

1. Audible breath: compare responses to two recordings of the same performance of a piece, one which includes the sound of the performer's breathing (often included in recordings of classical music) and the other without. Breathing could be suppressed or added in, even added in places which would be musically incongruous.

2. Different interpretations of the same work: comparing the influence of consistent musical structure in a composed work to the contributions and contrasts of different interpretations with different performer respiratory sequences.

3. Different listening attitudes: compare respiratory alignment for familiar and unfamiliar music (or even performed music, working with musicians), alertness and arousal as mediated with

listening while standing or lying down, and with different degrees of distraction, such as while reading or playing a game while music plays.

In the next two years, it will likely not be possible to test all of these factors, but each would be interesting to explore once respiratory adaptation is manageably measurable.

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