Cardiovascular, cerebrovascular and respiratory changes induced by different types of music in musicians and non-musicians: The importance of silence

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Abstract

Objective: Music might induce changes in the cardiovascular and respiratory systems of potential clinical use, particularly in modulating stress. We assessed the importance of tempo, rhythm, melodic structure, pause, individual preference, habituation, order effect of presentation, and previous musical training.

Design: Measuring cardiovascular and respiratory variables while listening to music.

Setting: University research laboratory for the study of cardiorespiratory autonomic function.

Patients: Twelve practising musicians and 12 age-matched controls.

Interventions: After a 5 min baseline, presentation in random order of 6 different music styles (first for a 2 min, then for a 4 min track), with a randomly inserted 2 min pause, in either sequence.

Main outcome measures: Breathing rate, ventilation, carbon dioxide, RR interval, blood pressure, mid-cerebral artery flow velocity, and baroreflex.

Results: Ventilation, blood pressure and heart rate increased, mid-cerebral artery flow velocity and baroreflex decreased with faster tempi and simpler rhythmic structures, compared to baseline. No habituation effect was seen. The pause reduced heart rate, blood pressure and minute ventilation – even below baseline. An order effect independent of style was evident for mid-cerebral artery flow velocity, indicating a progressive reduction with exposure to music, independent of style. Musicians showed greater respiratory sensitivity to the music tempo as compared to non-musicians.

Conclusions: Music induces an arousal effect, predominantly related to the tempo. Slow or meditative music can induce a relaxing effect; relaxation is particularly evident during a pause. Music, especially in trained subjects, might first concentrate attention during faster rhythms, then induce relaxation during pauses or slower rhythms.
Introduction

Music now plays an increasing role in several disparate areas. Music can reduce stress [1][2][3][4], improve athletic performance [4][5][6] motor function in neurologically impaired patients with stroke or parkinsonism [7][8][9], or milk production in cattle. [10]

Listening to music is a complex phenomenon, involving psychological, emotional, neurologic, and cardiovascular changes, with behavioural modifications of breathing [11][12]. Non musicians listen using the non dominant hemisphere, while musicians (probably more attentive) use the dominant hemisphere. [13] These responses, might be influenced by musical style (eg classical vs rock), melody, harmonic structure, rhythm and tempo, but also verbal content: for example, the brain asymmetry shown for language and melody perception has not been found in rhythm perception. [13] Heart rate, blood pressure, or respiration have been studied [1] [14][15], but so far, no comprehensive comparisons of autonomic, cardiovascular and respiratory changes to such a large range of music, order of presentation or the effect of a short interpolated pause, and also the responses related to musical training. Cardiorespiratory variables can be modified by rhythmic repetition of a prayer or a yoga mantra [16], or poetry recitation. [17] We therefore investigated listening to music for similar effects.

We investigated the responses to six types of music (with differing rhythmic, harmonic and melodic structure), in musicians versus non-musicians. We measured cardiovascular, respiratory and cerebrovascular variables their short-term reproducibility, habituation, and the non specific effect of a random order of presentation.

Methods

Subjects

The protocol was approved by the local Ethics Committee; all subjects gave informed consent. We studied 24 healthy righthanded caucasian subjects (mainly colleagues or medical students) (Table 1). Twelve had no previous special training in music (non-musician group, table 1), whereas 12 were advanced conservatoire students or post-conservatoire diplomates, with at least 7 years of continuous practice (musician group, table 1). The main instruments played were violin (4), piano (3), flute (2), clarinet (1), trumpet (1) and bass (1). Some had experience with other modern instruments (electric guitar (2) and drums (1)).

Table 1 - General data

<table>
<thead>
<tr>
<th></th>
<th>Musicians</th>
<th>Non musicians</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>5/7</td>
<td>7/5</td>
<td>ns</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>23±1</td>
<td>25±1</td>
<td>ns</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>61.5±3.9</td>
<td>62.7±2.3</td>
<td>ns</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.8±2.5</td>
<td>169.7±2.1</td>
<td>ns</td>
</tr>
<tr>
<td>Body Mass Index (Kg/m²)</td>
<td>20.8±0.7</td>
<td>21.7±0.5</td>
<td>ns</td>
</tr>
</tbody>
</table>

Study protocol

All tests were carried out supine in a comfortable temperature humidity and light, with subjects wearing headphones (keeping eyes closed) [18]. The subjects avoided tapping with finger or foot
(to avoid aritfactual entrainment) [19], confirmed by continuous visual monitoring. After a period of 20 min of quiet rest, we continuously monitored heart rate (RR interval) from the electrocardiogram (chest leads), and non-invasive beat-to-beat blood pressure by planaplanation tonometry at the radial artery (Pilot model, Colin tonometry, San Antonio, TX). This method faithfully tracks changes in invasive blood pressure. [20] Mid-cerebral artery blood flow velocity was monitored by a 2 MHz trans-cranial Doppler (TCD) probe at a depth 35-55 mm through the temporal window of the non-dominant side (DWL, Sipplingen, Germany). Respiratory movements were continuously evaluated by inductive plethysmography expressed as a percentage of baseline values. In a steady state the amplitude of this signal shows excellent intra-subject correlation with tidal volume recorded with a facial mask or a mouthpiece and a pneumotachograph [12], but avoids the respiratory modifications induced by such devices [12]. End-tidal carbon dioxide levels (CO2-et) were monitored by a nasal cannula and side-stream capnography (COSMOplus, Novametrix, Wallingford, CT).

Baseline recordings were taken for 5 minutes. Then, in random order, with no intervening pauses, presentations of 2 minute periods of: a) slow classical b) fast classical c) dodecaphonic , d) techno, e) rap, f) raga music began. Details of these music tracks are shown in table 2.

Then the tracks, were repeated in a different random order, but this time for 4 minutes. In addition, we recorded 2-minutes of silence, randomly inserted into either the short or long music sequences. Finally we asked the subjects to rate their preferences for the 6 music tracks.

In order to obtain a suitably long period of music with a stable character and tempo, we chose periods with a steady orchestral or rhythmic line, and then several identical sequences were appended one to another, to maintain a 2 or 4 min melodic and harmonic continuity.

<table>
<thead>
<tr>
<th>Style</th>
<th>Tempo (beats/min)</th>
<th>Harmonic structure</th>
<th>Melodic structure</th>
<th>Rhythmic structure</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raga</td>
<td>55</td>
<td>modal</td>
<td>modal</td>
<td>minimal</td>
<td>Debabrata Chaudhuri: introduction from “Raga Maru Behag”; from &quot;Sitar music meditations” Music for Pleasure Ltd, Feltham, UK, 1967</td>
</tr>
<tr>
<td>Classical slow</td>
<td>70</td>
<td>conventional*</td>
<td>conventional</td>
<td>present</td>
<td>Ludwig van Beethoven: &quot;Adagio molto e cantabile” from 9’ Symphony Op.125, 1823</td>
</tr>
<tr>
<td>Dodecaphonic</td>
<td>76</td>
<td>absent</td>
<td>absent</td>
<td>absent</td>
<td>Anton Webern: “Zart bewegt”, from &quot;Pieces forOrchestra” Op.6, 1909</td>
</tr>
<tr>
<td>Techno</td>
<td>136</td>
<td>conventional</td>
<td>rudimentary</td>
<td>strong, obsessive</td>
<td>Gigi D’agostino: “You spin me round” from “&quot;Tecno Fes vol 2”, Noisemaker, 2000</td>
</tr>
<tr>
<td>Classical Fast</td>
<td>150</td>
<td>conventional</td>
<td>conventional</td>
<td>strong, non-syncopated</td>
<td>Antonio Vivaldi: “Presto” from &quot;Estoate”, concerto for violin, orchestra and continuo n.2 Op.8, 1725</td>
</tr>
</tbody>
</table>

* Conventional relates to the musical culture of caucasian subjects
Tempo is measured in beats/min, where 1 beat = 1 black note

Data acquisition and analysis
All signals were continuously acquired on a personal computer (Apple Macintosh G3, Coupertino, CA), at a frequency of 600 samples/channel. Optical disk storage allowed further analysis. Breathing rate, relative tidal volume, minute ventilation and CO2-et were calculated for each breath. Mean values for heart period (RR interval) and systolic blood pressure were obtained, after...
discarding the first 30 seconds. Baroreflex sensitivity was calculated from the same sequences of RR interval and systolic blood pressure, by autoregressive power spectral analysis of RR interval and systolic blood pressures ("alpha index"). [21] This method is particularly well suited for relatively short-term sequences (2 or 4 minute).

We evaluated sympatho-vagal balance by the ratio between low (from 0.03 to 0.15Hz, LF) and high frequency components (0.15 to 0.40Hz, HF) of heart rate variability. [21] This ratio reflects sympatho-vagal balance only when the respiratory oscillations remain in the HF band. [22] To remove any spurious LF due to slow respiration, we calculated low- and high frequency power of the respiratory signal, and then removed from the RR LF power the proportion of the LF due to respiration. Therefore, the LF/HF ratio was obtained using LF oscillations not directly influenced by respiration.

**Statistical analysis**

Data are presented as means±SEM. Analysis of variance (ANOVA) for mixed design/repeated measures on 2 factors [23] tested the effects of different music types, of duration/repetition, for the 2 different groups. By looking at different aspects, or by recombining the data, several types of information could be obtained (see below). We also evaluated the relationship between each variable and the tempi of the tracks by linear regression analysis.

**Effect of music style**

An exceedingly high number of potential factors can affect the cardiovascular response to music perception, so we chose to test the contribution of different factors by comparing different music styles (table 2): harmonic, melodic, or rhythmic structure (non-syncopated vs syncopated) and Tempo (ie rhythm speed). We graded the tracks according to each of these aspects, to determine which characteristics were important for the cardiovascular and respiratory responses. The randomization of order of presentation allowed independent unbiased assessment of these multiple factors.

**Effect of duration of the music and of repetition**

As a test of reproducibility, & habituation, we compared the initial 2 min sequence with the longer 4 min sequence, and also the initial versus final 2 min of 4 min tracks.

**Non-specific effect of exposure to music**

To identify any non-specific “order” effect we grouped all data in terms of order of presentation (ie regardless of the type of music presented) eg we grouped all data by the first track, the second and so on.

**Effect of music training**

We compared musicians versus non-musicians

**Results**

**a) Effect of different music styles**

The effects of different music styles are shown in figures 1 and 2. Faster tempi induced significant increases in ventilation, breathing rate, TCD, systolic and diastolic blood pressure, and heart rate (RR interval), tended to reduce baroreflex sensitivity and induced a progressive increase in the LF/HF ratio (supplemental figure 1). No significant changes were seen in CO₂-et . In contrast, slower music had proportionally less effect, and Raga induced a significantly larger fall in heart rate (increase in RR interval, p<0.01), - even compared to baseline, or any other music tracks.
These effects appeared to be dependent on the speed of the music rather than on the style, as for example classical and techno styles induced similar results when similarly fast; Raga, classical and dodecaphonic music, all similarly slow, reduced cardio-respiratory responses.

The breathing rate (figure 3), and the LF/HF ratio (supplemental figure 2) increased significantly with increasing tempo. No other aspects of the 6 music tracks appeared to play a relevant role. There ratio tempo/breathing rate was 4.1±0.3 (raga), 4.7±0.4 (classical slow), 5.2±0.3 (dodecaphonic) 6.5±0.4 (rap) 8.0±04 (techno) and 8.7±0.6 (classical fast). These results were not influenced by the music preferences of the subjects. Table 3 shows that their preferences for structured harmonic and melodic music were independent of the tempo.

<table>
<thead>
<tr>
<th>Musicians</th>
<th>Non musicians</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical Fast</td>
<td>1.5±0.2 (1)</td>
<td>1.3±0.2 (1)</td>
</tr>
<tr>
<td>Classical Slow</td>
<td>1.7±0.2 (2)</td>
<td>2.1±0.3 (2)</td>
</tr>
<tr>
<td>RAP</td>
<td>3.3±0.3 (3)</td>
<td>3.7±0.3 (3)</td>
</tr>
<tr>
<td>Raga</td>
<td>4.3±0.3 (4)</td>
<td>4.0±0.3 (4)</td>
</tr>
<tr>
<td>Techno</td>
<td>4.6±0.3 (5)</td>
<td>4.6±0.5 (5)</td>
</tr>
<tr>
<td>Dodecaphonic</td>
<td>5.4±0.2 (6)</td>
<td>5.2±0.3 (6)</td>
</tr>
</tbody>
</table>

The numbers in brackets indicate the score of each musical style (1 being best, 6 being worst)

b) Effect of repetition of music and reproducibility

There was no significant overall difference (ANOVA) of later repetition of any individual track, with the notable exception of TCD, which was markedly and significantly (p<0.001) lower on the second presentation, even below baseline. Except for TCD, repetition of the music induced no other habituation even when administered for a longer period (4 vs 2 min), and the same music style (in short vs longer tracks) induced nearly identical effects. Finally, the effects of the first 2 min of a 4 min track showed no significant differences from the final 2 min, or from the original 2 min version, (except for TCD, see above).

c) Non-specific effect of exposure to music (order effect)

When we recombined the entire data set by order of presentation (first music track, second music track, and so on) we observed (figure 4) a significant order effect, independent of music style. This overall effect was highly significant for TCD, which showed a slight increase at the beginning of the experiment, and then progressively dropped below baseline. Breathing rate and ventilation also showed an initial increase at the beginning of the experiment, with subsequent inconsistent changes. Systolic and diastolic pressures and heart rate showed trends similar to TCD; these did not reach statistical significance. No identifiable trends were seen in CO2-et, baroreflex sensitivity or LF/HF ratio.

Effect of a randomly inserted pause between music tracks

In contrast, the 2-min rest randomly introduced into the sequence of tracks, was characterized by the lowest systolic and diastolic blood pressure, heart rate (longest RR interval) and minute ventilation and (in musicians) LF/HF ratio, and the highest CO2-et (figures 1 and 2 and supplemental figure 1).
d) Effect of music training

There were no major differences between musicians and non-musicians, but the ANOVA model showed both at baseline, and also during listening, that musicians had a significantly lower respiratory rate (p<0.05), and increased their breathing rate more than non-musicians in response to increasing tempi (figure 3). During the pause, they showed lower respiratory rate and lower LF/HF ratios than controls (figure 3, and supplemental figure 2). Table 3 shows that the order of music preferences was identical in the two groups of subjects. No other aspects of the music tracks induced differences in the two groups.

Discussion

Main findings

This study has revealed several novel features concerning the effects of music on autonomic control of breathing and circulation, which may have wider implications, beyond cardiorespiratory regulation.

There is an important order effect in both musicians and non-musicians, which, to our knowledge, has been previously neglected.

Passive listening to music accelerates breathing rate, increases blood pressure and heart rate and the LF/HF ratio (thus suggesting sympathetic activation) proportional to the tempo, and perhaps the complexity of the rhythm. The music style, or an individual’s music preference seems less important.

Musicians breathe faster with faster tempi, and had slower baseline breathing rates than non-musicians.

A randomly inserted short pause (2min), decreases blood pressure, minute ventilation, heart rate, and the LF/HF ratio in trained subjects. This relaxation effect is even greater than that seen at the end of 5 minutes of quiet relaxation at baseline. There was no evidence of autonomic habituation to any given music, except for cerebral blood flow, which progressively fell with time, regardless of the order of music presentation. These effects were consistent during longer or shorter presentations of the same music.

At variance with the rest of the data, The TCD showed a significant reduction with progression of exposure to music (order effect). Under resting conditions cerebral blood flow is mainly responsive to local metabolic demand. Thus, during long continuous exposure to music (figure 4), and particularly, during a pause (figure 1), a marked drop in TCD velocity may reflect reduced metabolic demand, which is not in contrast with previous findings of a selective increase in cerebral blood flow in specific areas during listening to music. [24] A previous study (during a short-term comparison) reported a slight increase in response to music in the right hemisphere [13] which is essentially confirmed in our study, particularly during more rhythmic tracks (figure 1) and in comparison to the pause. Due to technical limitation, we could not assess hemispheric differences in our study. However, such differences were small in quantitative terms. [13]

Whether the effects observed in our study were secondary to respiratoy entrainment [25] or to a direct sympathetic stimulation by arousal remains speculative. The ratio tempo/respiratory rate was close to the music structure in the slowest (raga and classical slow: about 1 breath per 4 black notes) and fastest tracks (techno and classical fast: 1 breath per 8 black notes), suggesting respiratory entrainment, but this was clearly absent in the intermediate rhythms. All variables were
related to the tempo, but not to music preference. This suggests that perhaps both respiratory 
entrainment by music and direct arousal were coexistent and interrelated: in fact, the increase in 
breathing rate in itself might have contributed to increase sympathetic activity [26].

Thus, overall, we observed an arousal effect proportional to the speed of the music, with slower 
rhythms inducing relaxation. Even greater relaxation was induced by a randomly inserted 2 minute 
pause, suggesting that a pause (or perhaps a slowing of music tempo) may have a crucial 
importance in determining some of the relaxing effects of music.

One might speculate whether specific types of music could be potentially useful as a clinical tool to 
modulate breathing and sympathetic arousal. Classical Greek philosophers thought that music and 
sports were two fundamental aspects of health. [27] Newer studies emphasise the value of music in 
lowering stress. [2][3][4] Meditative or slow classical music can lower neurohumoral markers of 
stress [1] [14] and thrombotic activity [1] at rest, in contrast to the increase found by physical 
exercise. [28]

How might music resemble other relaxation techniques

Previous studies suggested that meditative music decreased heart rate, blood pressure, and plasma 
catecolamines. [1] Our study confirmed these findings only partially. Slow meditative music 
increased RR interval but had no significant effect on respiration and blood pressure. Instead, our 
data showed a consistent increase in all these variables (from baseline, or from the pause) with 
increasing speed of music. In order to maintain a stable style of music we (and most previous 
researchers) selected periods of music with a relatively constant speed and rhythm (see methods). 
However, composers (even of techno music) always include pauses, even in the fastest rhythms, 
and in general alternate fast and slow tempi. Interestingly, it was precisely during this short 
intermission, rather than during music, that we observed the greatest evidence of relaxation, as 
compared to baseline or music tracks.

One speculative possibility arising from this effect is that music, and particular fast tempi, induce an 
arousal [25] resulting from focussed attention, similar to the effect of reading silently. [22][29] This 
could be induced or amplified by respiratory entrainment. During a pause, or slower tempo, arousal 
(and perhaps attention) is released, leaving the subject in a state of relaxation. In a typical 
relaxation technique [30] the subject is encouraged first to concentrate attention on a specific 
physical or mental object (eg during music in the present case). Then, the subject is encouraged to 
release attention (eg during pause). This final condition is important in achieving a relaxed state. 
Thus, music may achieve the same effect by alternating faster and slower rhythm or pauses, or 
simply after its cessation. Other studies have proven that, at any given level of physical exercise, 
music (particularly at faster tempi [6]) can lower heart rate and the level of perceived exertion 
[4][5][6] by a similar distracting effect.

Conclusions

Even short exposure to music can induce measurable and reproducible cardiovascular and 
respiratory effects, leading to a condition of arousal or focussed attention that is proportional to the 
speed of the music, and that could be induced or amplified by respiratory entrainment by the music 
rythm and speed. This effect is independent (at least under the experimental conditions of our 
study) of an individual’s preference or of repetition/habitation, and is clearer when the rhythmic 
structure is simpler, and was perhaps less evident in non-rhythmic or syncopated music. A pause in 
the music induces a condition of relaxation greater than that preceding the exposure to music, and 
leads one to speculate that music may give pleasure (and perhaps health benefit) as a result of this
controlled alternation between arousal and relaxation. It may be viewed as an alternative technique of relaxation or meditation, without involving the active participation of the subject. Previous training in music enhances the subject’s ability to respond to music rhythm, since musicians learn to synchronise breathing with the music phrase. In conclusion, the present study indicates that appropriate selection of music, by alternating fast and slower rhythms and pauses, can be used to induce relaxation and reduce sympathetic activity, and so be potentially useful for cardiovascular disease.

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Competing interests
None declared

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Figure Legends

Figure 1
Responses in breathing end-tidal CO₂, minute ventilation and transcranial mid-cerebral Doppler flow velocity (TCD) for each intervention (CL: classical, DODEC: dodecaphonic).
*: p<0.05, **: p<0.01, ***: p<0.001 vs Baseline; #: p<0.05, ##: p<0.01, ###: p<0.001 vs Pause.

Figure 2
Responses in blood pressure (BP), inter-beat period (RR interval) and baroreflex sensitivity for each intervention. Symbols as in Figure 1. The tracks are arranged in order of increased tempo.

Figure 3
Relationship between music tempo and breathing frequency for musicians (open circles with standard error and dotted regression line) and non-musicians (solid circles with standard error and solid line). Abbreviations as in Figure 1. Musicians show larger responses to tempo.

Figure 4
Responses plotted by presentation order rather than music style. X₁ is baseline, X₂ to X₁₄ are the serial responses to 6 music tracks played twice plus 1 pause, all presented in random order. Note progressive trends related to order of presentation.
References


Breathing Frequency
(breaths/min)

Non musicians: $r=0.15$, $p:ns$

Musicians: $r=0.35$, $p<0.001$

Tempo (beats/min)

PAUSE 0
RAGA 50
DODEC. 100
RAP
TECHNO 150
CL.SLOW
CL.FAST
Supplemental figure 1
Responses in LF/HF ratio of spectral analysis of heart rate variability for each intervention (CL: classical, DODEC: dodecaphonic). *: p<0.05, vs Baseline; #: p<0.05 vs Pause.
Supplemental figure 2
Relationship between music tempo and LF/HF ratio (open circles with standard error and dotted regression line) and non-musicians (solid circles with standard error and solid line). Abbreviations as in Figure 1. Musicians show larger responses to tempo.
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