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Multidimensional scaling of emotional responses to music: The effect of musical expertise and of the duration of the excerpts

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Musically trained and untrained listeners were required to listen to 27 musical excerpts and to group those that conveyed a similar emotional meaning (Experiment 1). The groupings were transformed into a matrix of emotional dissimilarity that was analysed through multidimensional scaling methods (MDS). A 3-dimensional space was found to provide a good fit of the data, with arousal and emotional valence as the primary dimensions. Experiments 2 and 3 confirmed the consistency of this 3-dimensional space using excerpts of only 1 second duration. The overall findings indicate that emotional responses to music are very stable within and between participants, and are weakly influenced by musical expertise and excerpt duration. These findings are discussed in light of a cognitive account of musical emotion.

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Music is a complex acoustic and temporal structure that induces a large variety of emotional responses in listeners. Although the richness of these responses is what motivates an engagement with music, relatively few studies have been devoted to understanding their psychological foundation. This situation is currently changing, as attested by the publication of an increasing number of studies investigating emotional responses to music at both behavioural level (Gabrielsson & Juslin, 1996, 2003; Gabrielson & Lindstrom, 2001; Gabrielsson, 2001; Robinson, 1997; Sloboda & Juslin, 2001) and neurophysiological level (Bartlett, 1999; Peretz 2001; Scherer & Zentner, 2001, for reviews). Two main issues of interest can be distinguished in this domain. The first concerns the content of emotional responses to music, the second the nature of the process involved in these responses. The present study deals with both issues.

The nature of emotions induced by music has been a matter of much debate. Preliminary empirical investigations have demonstrated that basic emotions, such as happiness, anger, fear, and sadness, can be recognised in and induced by musical stimuli in adults and in young children (Cunningham & Sterling, 1988; Dolgin & Adelson, 1990; Kastner & Crowder, 1990; Tergwogt & Van Grinsven, 1991). The experimental methods used consisted in matching emotional responses with either linguistic labels or pictures of expressive faces, or involved electrophysiological reactions to music. All of these methods converge to demonstrate a strong consistency between participants, as long as musical excerpts were chosen to convey very basic emotions. The conclusion that music induces three or four basic emotions is encouraging for scientists but it is far from compelling for music theorists, composers, and music lovers. Indeed, it is likely to underestimate the richness of the emotional reactions to music that may be experienced in real life. The question of whether emotional responses go beyond four main categories is a central issue for theories of human emotion (see Averill, 1994; Ekman, 1994; Smith & Ellsworth, 1985).

An alternative approach is to stipulate that musical emotions evolve in a continuous way along two or three major psychological dimensions. A lot of previous research has established a 2-dimensional structure of emotion for facial expressions (Abelson & Sermat, 1962; Osgood, 1966), voice perception (Green & Cliff, 1975), and affect words (Russell, 1978, 1980). According to Russell (1980) our emotional knowledge are organised and summarised into a cognitive structure that helps, in turn, to shape the perception and interpretation of events. In his circumplex model of affect, Russell (1980) proposed a cognitive structure of affective experience that relied on the interrelationship between affective concepts (words with hedonic meaning). The affective space he obtained by using three different scaling techniques revealed two orthogonal and bipolar dimensions of pleasure-displeasure and degree of arousal. Beyond arousal and pleasantness, the dimensions that emerge were often difficult to interpret, and when interpretable, they vary from study to study (Smith & Ellsworth, 1985).

In the music domain, an attempt to model the perception of expressive content of Western music in multidimensional space has been developed (Hevner, 1935; Juslin, 2001; Madsen, 1997; Russell, 1980; Schubert, 1996, 2001, 2004) and specific neurophysiological reactions associated with the arousal and valence dimensions were also reported (Schmidt & Trainor, 2001; Tsang, Trainor, Santesso, Tasker, & Schmidt, 2001). Only a few studies however attempted to confirm that arousal and valence were actually the most important determinant of emotional responses to music. In Wedin (1969, 1972a, 1972b) musical excerpts were rated on a number of semantic scales defined by emotionally coloured adjectives. Factor analysis then extracted the dimensions accounting for the evaluation. In Imberty (1979, 1981), a 2-dimensional structure was found by analysing the semantic contents of words freely associated by listeners to musical excerpts. In both groups of research, arousal and emotional valence emerged as the main dimensions of emotional responses to music. In each case, a third dimension was found but it corresponded to ''solemnity-triviality'' in Weldin studies and was associated to figural gestures in Imberty (1979). More recently, Canazza, De Poli, Vidolin, and Zanon (2001) presented participants with an excerpt of Mozart's *Clarinet Concerto* (K 622) that was interpreted and recorded with different levels of expressivity. Participants were asked to use a set of sensorial adjectives (e.g., light, soft, dark, hard...) to express the emotion they felt the excerpt possessed. Using multidimensional and factorial analyses, they obtained a semantic 2-dimensional space of musical expressivity in which two dimensions appeared: one called ''kinematics'' that corresponded to the tempo parameter and another called ''energy'' related to the intensity parameter. Such a kinematics-energy space provides useful information on how expressiveness is organised in the listener's mind. Interestingly, this study indicates that kinematics aspects could be a main determinant of participants' judgements on musical expressiveness.

A common feature of these studies was to investigate emotional responses to music by using linguistic labels. The use of verbal labels is potentially problematic since it can encourage participants to simplify what they actually experience (Scherer, 1994). Some philosophers even argued that musical emotions are definitely ineffable (Jankélévitch, 1974, 1983/2003). As nicely coined by the composer, Felix Mendelssohn, the emotion induced by music could be so rich that even language would not be able to account for it. If this was the case, using linguistic labels in empirical research could result in missing important aspects of musical emotion.[1] The first goal of the present study was to investigate the emotion conveyed by musical pieces without using linguistic

[1] In the place of linguistic responses, it is also possible to record electrophysiological responses to musical stimuli (Khalfa, Peretz, Blondin, & Robert, 2002; Krumhansl, 1997). These methods are promising, but it is uncertain whether they are refined enough to account for the subtlety of musical emotions.

responses. Participants were encouraged to entirely focus on their own emotional experience of the musical excerpts and to group those that conveyed similar subjective emotions. A simple rule transformed the partition obtained into a dissimilarity matrix: stimuli grouped together were set with a dissimilarity of 0, while everything else was set to 1. Multidimensional scaling (MDS) method was then used to analyse the psychological dimensions underlying this matrix.

The instruction we used encouraged participants to focus on induced emotions and not to recognise the emotional information encoded in the music. That it to say, the task prevents using labels that can bias emotional judgement The difference between induced and perceived emotion has been a matter of debate in the literature of facial expression, and the debate has transpired in the music domain as well (Gabrielsson, 2001; Scherer & Zentner 2001). Of course, asking participants to focus on induced emotions does not guarantee that they actually respond more on the basis of what they experienced than on the basis of the expressions they recognise in the stimuli. It is even unclear whether both aspects of emotional experience might be separable. In order to better specify the type of emotion our task was tapping into, we ran a pilot experiment that was designed to shed some light on this issue. Participants were first required to evaluate the emotions they felt on bipolar semantic scales to while listening to musical excerpts. They were then asked to evaluate on the same scale the emotions presumably felt by a representative sample of listeners of the matched age and sociocultural level. An extremely high correlation was found between both evaluations with $r(34) = .93$, $p < .001$. This suggests that induced and perceived emotions, if different, are likely to be two different faces of the same coin. We thus will consider in the context of this article, that participants' responses expressed emotions they perceived in the stimuli, either on basis of their ability to recognise expression in music, or on the basis of the emotion they felt, or, more probably, on a mixture of both phenomena. The first aim of the study was to assess the degree of consistency in emotional responses observed with this method, and to further specify the psychological dimensions that govern these responses.

A second main broad issue of the study relates to the mechanisms that govern emotion. Arguments for the contribution of cognitive processes to emotional responses are clearly favoured by research in music cognition (see Bever, 1988; Jackendoff, 1992; Meyer, 1956, 2001). Following Mandler's (1975) theory of emotion, Meyer (1956) argued that emotional responses to music depend upon whether the musical pieces fulfil perceptual and cognitive expectancies generated by the opening of the piece. Musical expectancies result from processing several features, such as harmony, rhythm, melody, and thematic relationships cognitively. This processing is believed to occur automatically at an implicit level (for a review, see Tillmann, Bharucha, & Bigand, 2000). A cognitive account of musical emotion is supported by empirical studies showing that emotional responses are systematically associated with the presence of specific musical features (Sloboda, 1991, 1992; for a review, see Gabrielsson, 2001; see Sloboda & Juslin, 2001). For example, musical features such as modulation, grace notes, and harmonic progressions, are often associated with emotional responses in the verbal reports of participants (Sloboda, 1991). In a related vein, Peretz, Gagnon, and Bouchard (1998) demonstrated that rhythm and modality (major vs. minor) contribute to happiness or sadness. These studies pointed out that part of the emotional response to music results from the cognitive processing of musical structures (key, modalities, rhythm), which are known to be expressive in the context of the Western musical system. The precise organisation of these cognitive processes, however, remains unspecified.

This cognitive account has recently been challenged by two sets of data. Emotional responses were shown to rest on a very fast acting mechanism, so that 250 ms of music may suffice to distinguish happy from sad excerpts (Peretz et al., 1998). This suggests that some basic emotions might function like subcortical reflexes, without cortical mediation. The affective system is faster and developed earlier than the cognitive system (Reiman, Lane, Ahern, Davidson, & Schwarz, 2000; Zajonc, 1984). Independence between the affective and cognitive systems has been demonstrated in the visual domain (LeDoux, 2000). Cerebral lesions have been found to alter the recognition of facial expressions while the ability to identify faces was spared (Adolphs, Tranel, Damasio, & Damasio, 1994; Adolphs et al., 1999; Lane, Reiman, Ahern, Schwartz, & Davidson, 1997). In the field of music, IR, a brain-damaged patient who suffers from considerable deficits in music cognition, was shown to be able to discriminate between happy and sad excerpts while being unable to determine whether the music was familiar or not (Peretz et al., 1998; Peretz, Blood, Penhume, & Zatorre, 2001). Moreover, IR performed similarly to controls when differentiating sad from happy excerpts of extremely short duration. This suggests that severe deficits in the cognitive processing of music may leave emotional responses unimpaired.

The second main issue of the present study was to further investigate the influence of excerpt duration on emotional response. The experimental method used enabled us to specify which dimension of musical emotion would be processed first. It was likely that the emotional valence of music, which seems to be associated with the processing of Western harmony (major vs. minor), would require more time to be processed than arousal, which is linked to dynamic aspects of musical stimuli.

The final issue of the present study was to evaluate the effect of musical expertise. It is usually believed that musical experts process musical structure in a more refined way than nonmusicians. This issue has been challenged by a large number of empirical studies showing that nonmusicians respond to subtle musical structure in a comparable way to those with musical training (for a review, see Bigand & Poulin-Charonnat, in press). It is thus of critical importance to further investigate whether the emotional experience of the two groups is similar.

To summarise, the present study investigates three main issues for the study of musical emotion. Experiment 1 was designed to outline through MDS the psychological dimensions that govern emotional responses to Western music. Experiments 2 and 3 assessed how a considerable shortening of excerpt duration would modify the structure of emotional reactions. In addition, all experiments were run with musicians and nonmusicians in order to evaluate the influence of musical expertise on emotion.

EXPERIMENT 1

Method

Participants. A total of 19 participants performed the two experimental sessions. Of these, 9 did not have any musical experience and are referred to as nonmusicians and 10 were graduate music students and are referred to as musicians.

Material. A sample of 27 musical excerpts of serious nonvocal music was selected by music theorists and psychologists according to several constraints (see footnote 1). All excerpts were expected to convey a strong emotional experience. They were chosen to illustrate a large variety of emotions, and to be representative of key musical periods of Western classical music (baroque, classic, romantic, and modern) as well as of the most important instrumental groups (solo, chamber music, orchestra). This final constraint is of methodological importance since it helps to neutralise any confound effect between the structural surface similarity and the emotional similarity of excerpts. As much as possible, we avoided selecting excerpts that were too famous (Vivaldi's *Four Seasons*, Barber's or Albinoni's *Adagio*, Holst's *Planets*). Appendix A displays a short description of the 27 excerpts used as stimuli. They corresponded either to the beginning of a musical movement, or to the beginning of a musical theme or idea. An average duration of 30 s duration sounded appropriate for the purpose of Experiment 1.

Apparatus. All excerpts were real performances taken from commercial compact disk (CDs). They were played by a mono file at 16 bits and 44 kHz. The overall loudness of the excerpts was adjusted subjectively to ensure a constant loudness across the experiment. The sound files were represented on the computer screen by small loudspeaker icons in a Powerpoint file. The position of each loudspeaker on the screen was chosen at random. Each participant worked on a different Powerpoint file and listened to the excerpts by clicking on the icons.

Procedure. Participants were presented with a random visual pattern of 27 loudspeakers, representing the 27 excerpts. They were required first to listen to all of these excerpts and to focus their attention on their private emotional experience. They were then asked to look for excerpts that induced similar emotional experience (whatever that may be) and to drag the corresponding icons in order to group these excerpts. They were allowed to listen to the excerpts as many times as they wished, and to regroup as many excerpts as they wished. A second experimental session was performed 2 weeks later. It followed the same procedure. Each session lasted about 40–50 min, on average. After the experiment, participants were also invited to describe verbally the emotions that governed their grouping.

Results

The first analysis concerned the number of groups produced by participants. Participants distinguished an average of 8 groups (7.68 for session 1, and 7.74 for session 2). Musicians did not produce more groups than nonmusicians. The percentage of excerpts that were grouped differently in sessions 1 and 2 was low (12%) but significantly higher for nonmusicians, (15%), than for musicians, (9%), $F(1, 14) = 8.34$, $p < .02$.

The groupings of participants were then converted into a 27 $\times$ 27 matrix of co-occurrence. Each cell of the matrix indicated the average number of times that two excerpts were grouped together. The subtraction of the average matrix of occurrence from 1 resulted in a matrix of dissimilarity. The matrices obtained for sessions 1 and 2 were highly correlated for musicians, $r(349) = .87$, $p < .001$, and for nonmusicians, $r(349) = .78$, $p < .001$. The correlation between the matrices of both groups was $r\ (349) = .83$, $p < .001$. Given the strong consistency of responses, the four matrices were fused. The resulting matrix was analysed with MDS and cluster analysis methods.

Multidimensional scaling. The matrix was processed by the EXSCAL MDS program (Winsberg & Caroll, 1989). This model postulates that the distance *dij*, between the ith and the jth stimuli is given by

$$D_{ij}\left[\sum_{r=1}^{R}(Xir - Xjr)^2 + Si + Sj\right]^{\frac{1}{2}}$$

where *Xir* is the coordinate of the ith stimuli on the *r*th dimension and *r* is the number of dimensions. In this model, in addition to *r* common dimensions, the stimuli can have a unique dimension, denoted *Si*, not shared by other stimuli. A maximum likelihood criterion, named BIC and a study of the stress value (Borg

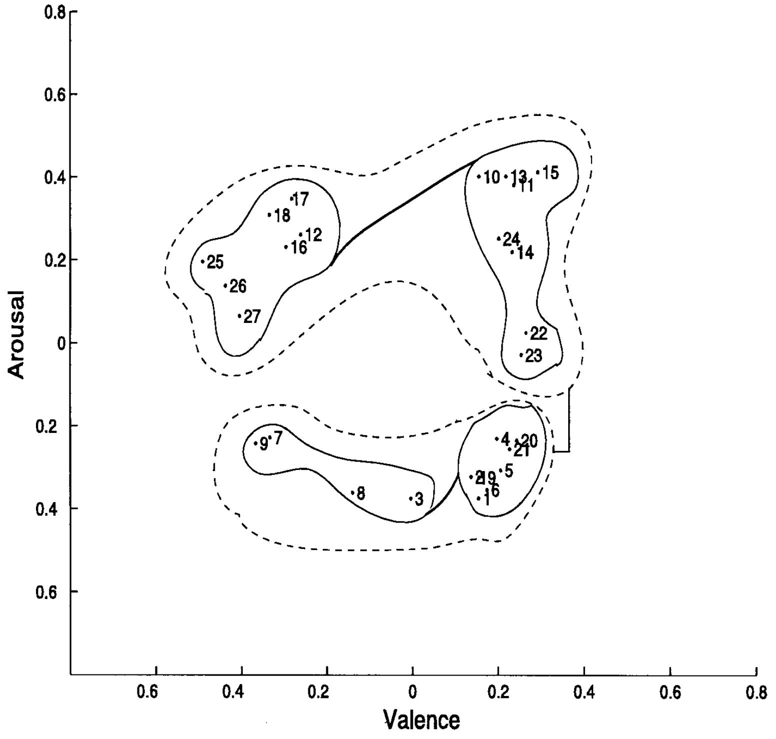


Figure 1. Geometrical solution for the 27 excerpts, resulting from MDS of Experiment 1 data. The main outcome of the cluster analysis is superimposed on the MDS solution with dashed lines representing the first two main clusters, and solid lines, the two subordinates clusters.

& Groenen, 1997) was used to determine the number of dimensions of the space. Both methods indicated a 3-dimensional space with specificities. Adding the third dimension to the model increases the explained variance from 73% to 83%.

The location of the 27 excerpts along the two principal dimensions is represented in Figure 1.[2] The vertical axis opposes musical excerpts that varied obviously by their arousal level (with low arousal pieces at the bottom, and high arousal pieces at the top). The horizontal axis presumably opposes musical excerpts that differ by their emotional valence (with positive valence on the right and negative valence on the left). The third axis tends to oppose pieces with broad and regular melodic contours from those that proceed harmonically or by broken arpeggios.

[2] For the sake of convenience, the third dimension is not represented here.

A bootstrap analysis was performed to assess the instability of the location of excerpts in this emotional space. A new MDS space was created by randomly selecting 30 subjects, with replacement (a same subject can be used many times, while others never). This technique was repeated 200 times. Each space was rotated towards the same target. The greater the variability between subjects, the more each space must be different, and vice versa. The 200 spaces were superimposed on a single representation. The position of each excerpt in these 200 analyses defined a cloud of points on this single representation. The size of the ''cloud'' expresses the stability of each excerpt in the three dimensional space. As illustrated by Diagram 1 (Appendix A), the surfaces covered by the ellipses were fairly small, providing evidence for the reliability of the geometrical representation.

Finally, the MDS solution was compared with a cluster analysis performed on the emotional matrix. The main clusters isolated at the top of the dendogram were superimposed on the MDS solution in Figure 1. The two largest groups opposed pieces of different arousal level. The next two groups contrasted pieces of different emotional valence. This analysis delineated four main groups of pieces varying by their dynamic and emotional valence, and roughly corresponding to ''happiness'' (dynamic and positive valence), ''serenity '' (low dynamics, and positive valence), ''fear and anger'' (high dynamics and negative valence), and sadness (low dynamics and negative valence). Subtler categorisation was found within each of these groups.

To further investigate the psychological meaning of these dimensions, a control experiment was run with 19 musically untrained listeners from the University of Burgundy. They were asked to order the 27 excerpts on a single continuous dimension (varying from -100 to $+100$) that corresponded either to an ''arousal dimension'', an ''emotional valence'' dimension, and a ''pleasantness'' dimension. The average coordinates obtained for each of these dimensions separately with the control group was then correlated with the coordinates of the excerpts revealed by the MDS and illustrated in Figure 1. Correlation was $r(25) = .94$, $p < .001$ for the arousal dimensions, and $r(25) = .82$, $p < .001$ for the emotional valence dimensions. The pleasantness judgements were not correlated to the emotional valence dimension, $r(25) = .08$, but were moderately related to the arousal dimension, $r(25) = .51$, $p < .01$. None of these judgements correlated with the third dimension revealed by the MDS.

Discussion

Experiment 1 provides some evidence that music induces straightforward emotions. Strong consistency within listeners was found between sessions 1 and 2 and between the two groups of participants, irrespective of their musical expertise. The data also confirmed that two main psychological dimensions govern emotional responses: arousal and emotional valence. The control condition contributed an important finding: The emotional valence dimension was not correlated with pleasantness judgements. This suggests that sad music is not systematically associated with unpleasant emotion and vice versa. This apparent paradox distinguishes the present finding from those usually reported in multidimensional scaling of emotion (see Smith & Ellsworth, 1985) and emphasises a specific characteristic of musical emotions. This apparent paradox is consistent with recent brain imagery studies showing that sad music may activate neural pathways involved in biological reward (Blood & Zatorre, 2001).

Experiment 1 also revealed that a third dimension contributes to emotional responses to music. This dimension contrasted pieces with different melodic gestures. A possible interpretation is that this dimension express the influence body gestures evoked by musical excerpts might have on perceived emotions. The link between music and movement is well established, and several authors have emphasised that musical affects arise in large part from their relation to physical patterns of posture and gesture (Damasio, 2003; Francès, 1956; Jackendoff & Lerdahl, in press). A large melodic arch should thus evoke slow, large and continuous gestures, while broken arpeggios may evoke discontinuous and more saccadic movements. Given that a considerable amount of emotional experience is presumably embedded in cortical sensory motor maps (Damasio, 2003), the evocation of gestures by music could have relevant influence on listeners' emotional experience. However, given the difficulty to describe with linguistic terms these kinetic emotions, it remains difficult to further investigate the emotional qualities associated with this third dimension.

The last important finding of Experiment 1 is that emotional responses to music were only weakly influenced by musical expertise. Both groups of musicians and nonmusicians produced an equal number of clusters, and their matrices of emotional similarity were highly correlated. This weak difference is all the more surprising given the complexity of the musical stimuli used.

All of these findings (i.e., test-retest reliability, strong consistency between two independent groups) suggest that processing musical emotions relies on robust processes that do not depend upon an explicit knowledge of Western music. Experiment 2 was designed to further investigate the nature of these processes by manipulating the time duration of the excerpts. According to Peretz et al, (2001), emotional responses can arise from a very fast process that does not necessarily involve complex cognitive mediation. This conclusion might, however, be qualified since arousal and emotional valence were confounded in her study, with all positive excerpts being of high arousal (''happy'' category) and all negative excerpts being of low dynamics (''sadness'' category). Accordingly, participants may have correctly performed the ''happy''-''sad'' distinction at 250 ms, by considering only the dynamics of the excerpts. The purpose of Experiment 2 was to evaluate how reducing the duration of the music to 1 s would affect the dimensionality of emotional response, and the location of the 27 excerpts in this space. We expected that only one dimension (arousal) would then contribute to the emotional response.

EXPERIMENT 2

Method

Participants. Twenty participants without musical training (referred to as nonmusicians) and 20 with an average of 10 years of musical training and instrumental practice participated in this experiment. None of them had taken part in Experiment 1.

Material and apparatus. The material and apparatus were identical to those described for Experiment 1, with the exception that musical excerpts were reduced to a duration of 1 s in the 1 s condition. The sections of 1 s were the beginnings of the original excerpts. Each 1 s excerpt began with a 50 ms fade-in and ended with a 50 ms fade-out to remove any acoustic clicks. A short description of the musical structure found in the first second of each of these 27 excerpts is provided in Appendix B.

Procedure. The experimental task was similar to that of Experiment 1. In session 1, participants were asked to group the 1 s excerpts that induced similar emotional experiences. A second session was performed 1 week later with the same participants who performed the task with the excerpts used in Experiment 1 (referred to below as the 30 s condition).

Results

The first analysis compared the number of groups produced by participants in sessions 1 and 2. Participants distinguished 6.73 and 7.44 groups on average, in the 1 s and 30 s conditions, respectively, and there was no influence of musical expertise. The number of changes in grouping between the 1 second and the 30 s conditions was 16.6% and 19.6%, on average, for musicians and nonmusicians, respectively. This difference did not reach significance.

The dissimilarity matrices obtained with musicians for the 1 s and 30 s conditions were highly correlated $r(349) = .76$, $p < .001$. Interestingly, the matrix of the 30 s condition was also correlated with the matrix obtained in Experiment 1, $r(349) = .71$, $p < .001$ for session 1, and $r(349) = .70$, $p < .001$ for session 2. This demonstrates a strong stability of the emotional response between two independent groups of participants. For nonmusicians, the correlation between the 1 s and the 30 s matrices was $r(349) = .70$, $p < .001$. In addition, musically untrained participants responded very similarly to musicians in the 1 s duration, $r(349) = .80$, $p < .001$ and in the 30 s duration, $r(349) = .87$, $p < .001$. Once again, the 30 s similarity matrix of Experiment 2 correlated significantly with the nonmusicians' matrix found in Experiment 1 for session 1: $r(349) = .87$, $p < .001$; and for session 2; $r(349) = .89$, $p < .001$.

Multidimensional scaling analyses were performed separately for each group and in each duration condition. In each case, a 3-dimensional solution provided a very good fit with the data. For musicians, the addition of the third dimension to the model increased the percentage of explained variance from 68% to 85% and from 67% to 80% in the 1 s and 30 s conditions, respectively. For nonmusicians, this percentage of variance increased from 77% to 87% for the 1 s and 30 s conditions. The location of the 27 excerpts along the first two spatial dimensions is represented in Figure 2 (see note 2). The first dimension contrasts musical excerpts of different arousal. The second dimension contrasts musical excerpts of different emotional valence. As already reported in Experiment 1, the third dimension tended to oppose excerpts beginning with a melodic interval (small melodic gesture) against those that begin with a chord (no melodic gesture). The geometrical solution found for the 30 s duration was very similar to that reported in Experiment 1.[3] An interesting new issue is the geometrical solution for the 1 s condition. On the whole, the location of the excerpts did not change considerably, except that the excerpts were further apart than in the 30 s condition.

Cluster analysis helped to highlight some other noticeable differences between the 1 s and 30 s conditions. The main outcome of this analysis was superimposed on the geometrical solution in Figure 2. With musicians, three main groups of equal size were found in the 1 s condition, with all the excerpts of low arousal forming a single cluster. In the 30 s condition, the cluster of low arousal excerpts split into two clusters: one of low dynamic and negative valence (excerpts 9,7,8,3), the other of low dynamic and positive valence (excerpts 19, 2, 20, 1, 6, 4, 21, 5). This difference suggests that musicians encountered some difficulties perceiving the emotional valence when the 1 s excerpts induced a low arousal. In other words, the distinction between ''sad'' and ''serene'' was rendered more difficult with short duration excerpts, as illustrated by the misallocation of excerpt 7.

The geometrical solution found for nonmusicians in the 1 s and 30 s conditions was globally similar to that of musicians. As summarised in Figure 2, the first three main groups of the 1 s condition differentiated excerpts of different arousal, irrespective of their emotional valence. When the excerpts are 30 s long, high arousal excerpts were split into two groups: one of negative emotional valence (25, 27, 18, 16, 26, 17, 12) and one of positive valence (10, 11, 13, 15, 24, 14, 22, 23). A similar phenomenon occurred for the excerpts of low arousal that split into a cluster of negative valence (9, 7, 8, 3) and a cluster of positive valence (19, 2, 5, 20, 21, 1, 4, 6), in the 30 s condition. This finding indicates a

[3] Bootstrap analyses were also performed in order to evaluate the degree of instability of these geometrical solutions. They confirmed a generally high stability for the MDS geometrical solutions.

slight difference between nonmusicians and musicians. In the 1 s condition, the former encountered some difficulty in distinguishing excerpts according to their emotional valence, while the latter encountered this difficulty mostly with excerpts of low arousal.

Discussion

Experiment 2 demonstrated that a considerable shortening of musical excerpts (30 s to 1 s) had only a weak effect on emotional responses. This finding is consistent with the conclusion of Peretz et al. (2001). It is possible however, that this weak effect of duration was due to a lack of sensitivity of the experimental method. Given that participants were not asked to compare all pairs of musical excerpts before responding, the resulting matrix of dissimilarity might capture only the most robust features of emotional experience. If time duration was influencing response in a more subtle way, the current method would not be refined enough to capture this effect. A third experiment was run to address this issue. This time, participants were presented with all possible pairs of 1 s excerpts (i.e., 351) and were asked to evaluate the emotional dissimilarity of the excerpts of each pair on a subjective scale. The geometrical solution produced by this method was compared with those found in the 1 s condition of Experiment 2.

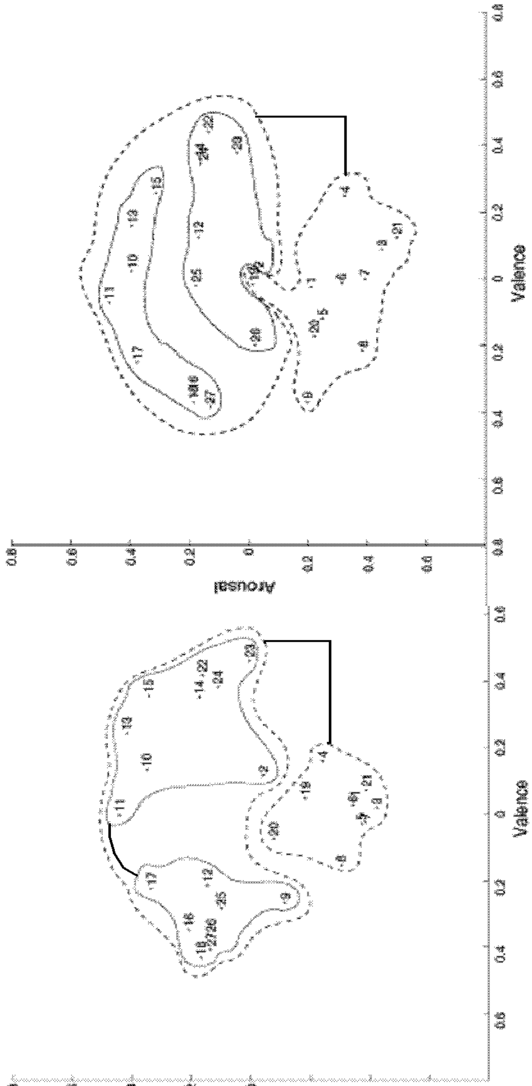
EXPERIMENT 3

Method

Participants. Fifteen participants without musical training and 15 with musical training and instrumental practice performed this experiment. None had participated in the previous experiments.

Material and apparatus. These were identical to Experiment 2 except that the 1 s excerpts were presented in pairs, with a 400 ms silence between the two excerpts.

Procedure. In the first part of the experiment, participants were familiarised with the 27 excerpts – they could listen to them as many times as they wished. In the second part, they were presented with 351 pairs of excerpts, played in a random order. After each pair, they were required to evaluate on a continuous scale how the emotion experienced for each excerpt differed. The scale included two extremities ranging from ‘‘different’’ on the left to ‘‘similar’’ on the right, and participants had to move a cursor along this continuous scale. Listeners could locate the cursor anywhere on this scale between the two extremities. The experiment lasted about 1 hour.


Arousal
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Arousal
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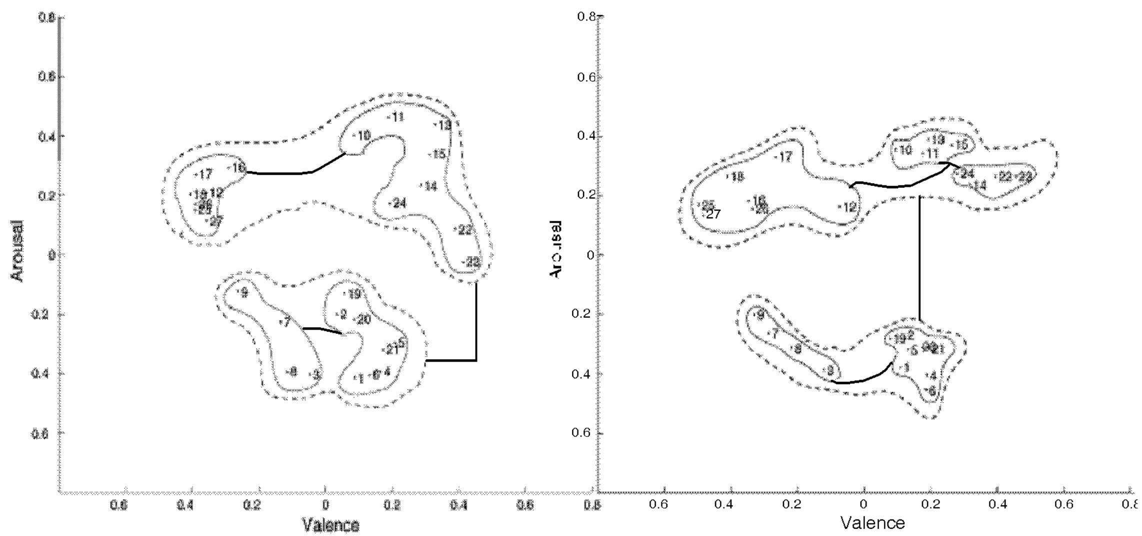

Figure 2. Geometrical solution for the 27 excerpts, resulting from MDS as a function of musical expertise and duration for the musicians (*Left*) and nonmusicians (*Right*) in the 1 s (*Top*) and 30 s condition (*Bottom*). The main outcomes of the cluster analysis are superimposed on the MDS space, with dashed lines representing the first two main clusters, and solid lines, the two subordinates clusters.

Results

For each listener, the emotional judgements were mapped on to an individual dissimilarity matrix. The average matrix for musicians and nonmusicians was significantly correlated, $r(349) = .86$, $p < .001$. Moreover, the matrices obtained in Experiment 2 in the 1 s condition were correlated with those of Experiment 3 for both musicians, $r(349) = .71$, $p < .001$, and nonmusicians, $r(349) = .73$, $p < .001$. The dissimilarity matrices of Experiment 3 were also significantly correlated with the matrices found in the 30 s condition of Experiment 2 for both musicians, $r(349) = .65$, $p < .001$, and nonmusicians, $r(349) = .65$, $p < .001$.

The dissimilarity matrix of each group was analysed using MDS and cluster analysis methods. The resulting geometrical solutions are illustrated in Figure 3, with the main outcome of the cluster analysis superimposed on the MDS representation. The MDS replicates the 3-dimensional solution previously found. As already reported, the first dimension contrasts pieces of different arousal, the second dimension those of different emotional values. The third dimension tended to contrast pieces that started with a melodic interval from those that started with a chord.

The positions of excerpts in the geometrical space were generally consistent with those reported in Experiment 2. Some differences were nevertheless highlighted by the cluster analysis. A careful comparison of Figures 2 and 3 shows that four main clusters of excerpts, rather than three, could now be distinguished for both musicians and nonmusicians. For musicians, the cluster comprising excerpts 2, 11, 10, 13, 14, 15, 22, 23, and 24 (i.e., high arousal and positive valence) in Figure 2 was split into two clusters in Figure 3: one cluster with the excerpts number (11, 12, 13, 15); and another with the excerpts number (10, 14, 22, 23, 24). This suggests that the ability of musicians to differentiate the valence of excerpts high in arousal was better expressed in Experiment 3 than in Experiment 2. The analysis of nonmusicians' data leads to a similar conclusion. In Experiment 3, three main clusters of excerpts with high arousal were revealed by the cluster analysis. They contrasted excerpts of negative, neutral, and positive emotional valence. Interestingly, the cluster of low arousal excerpts was unchanged for nonmusicians between Experiments 3 and 2.

Discussion

Experiment 3 replicated the data found in the 1 s condition of Experiment 2 using a different experimental procedure. Compared to Experiment 2, the only noticeable difference was that participants were better able to differentiate the emotional valence of high arousal excerpts. This suggests that the method used in Experiment 3 was, at best, marginally more sensitive than that used in Experiments 1 and 2.

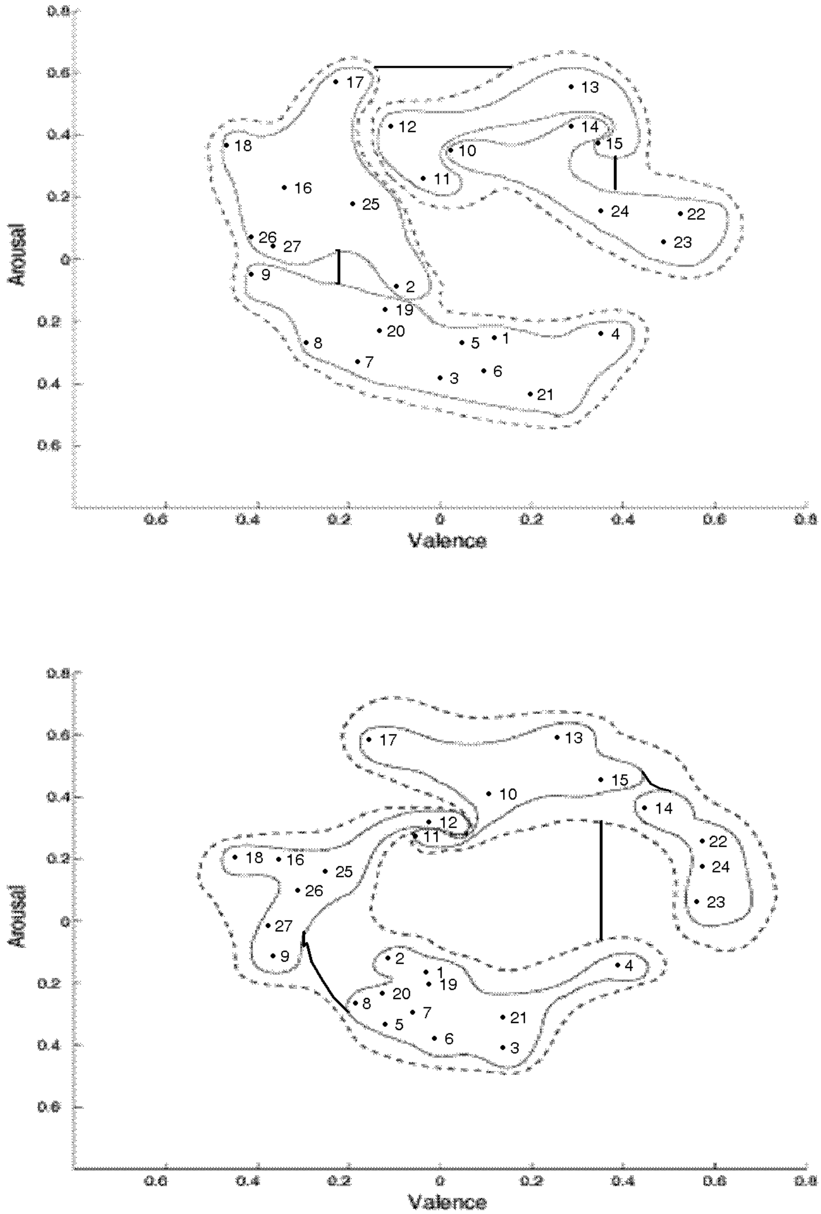

Figure 3. Geometrical solution for the 27 excerpts, resulting from MDS as a function of musical expertise in Experiment 3, with musicians at the top and nonmusicians at the bottom. The main outcomes from the cluster analysis are superimposed on the MDS space with dashed lines representing the first two main clusters, and solid lines, the two subordinates clusters.

GENERAL DISCUSSION

The present study investigated emotional responses to musical stimuli. First, the data confirm the strong consistency of emotional response between participants musicians and nonmusicians (Experiment 1) as well as between participants (Experiments 1 and 2). This stability was replicated even when the method involved a substantial change. The fact that this finding was obtained in an experimental task that explicitly encouraged participants to focus on their own emotional experience suggests that emotional responses to music are not subject to strong individual differences, and are reproducible within and between participants.

A second important feature of the current study is the provision of evidence that categorising musical excerpts on the basis of emotional experience transcends the usual criteria of musical categorisation, such as surface similarities, musical instrumentation, and musical style. As illustrated in Figure 1, some excerpts that were very close in the emotional space differ considerably in instrumentation and musical style. This is the case, for example, for excerpts 4 and 20 that correspond to a flute duo by W.-F. Bach and an orchestral piece by J. Brahms. Examples of this sort are numerous. They suggest that emotional experience may correspond to the most abstract level of musical categorisation.

The next important issue of the study has been to highlight the structure of the emotions induced by serious Western music. Two main approaches have been distinguished for musical emotions (Sloboda & Juslin, 2001). According to the categorical approach, listeners experience emotions as basic categories, such as ‘‘happiness’’, ‘‘serenity’’ ‘‘sadness’’, and ‘‘anger or fear’’. The present data confirm the relevance of these categories and further demonstrate that they are unlikely to be a by-product of linguistic labelling. However, the data also provide evidence showing that the emotional experience of participants was not restricted to these four basic categories. First of all, participants systematically grouped the 27 excerpts into more than four groups, and this grouping was very consistent within participants (Experiment 1). Second, the geometrical solutions displayed in Figures 1 and 2 underline that musical emotion cannot be fully accounted for by categories, and argue in favour of a multidimensional approach. The present data notably suggest that it is possible to manipulate emotions perceived in music in a continuous way along the one or the other dimension while keeping the other constant. For example, playing the excerpts 9, 7, 8, 3, 1, and 6, results in a continuous shift from depressed towards serene emotions, while maintaining an almost constant rate of arousal. In a same way, playing excerpts 1, 6, 5, 20, 23, 22, 14, 24, and 15, results in a continuous shift from serenity to jubilation, without changing the emotional valence. Finally, the present study revealed a third dimension that may link perceived emotions with body posture and gestures. This finding is consistent with the kinematics dimension found by Canazza et al. (2001), and more generally with the importance of movement for human emotions (see Damasio, 2003; Heider & Simmel, 1994).

A further intriguing focus of the present data is the time course of emotional responses. A previous study by Watt and Ash (1998) showed that 3–5 s extracts of orchestral interludes from Wagner operas were quite sufficient to generate consistent, and emotionally relevant, categorisations in listeners. Peretz et al. (2001) went one step further by showing that 250 ms music was enough to differentiate sadness from happiness. This provocative finding can be partly explained by the fact that participants were required to perform a forced-choice decision, contrasting musical pieces that differ by both arousal and valence. The important finding of the present study was that the emotions perceived in 1 s musical excerpts were highly similar to those experienced with longer excerpts. The present data thus extends the findings of Peretz et al. (2001) to a larger set of complex musical stimuli. They further suggest that extremely short duration is likely to impair the processing of the emotional valence of musical excerpts of a low dynamic. At first glance, this finding may sound extremely surprising. In half of the cases, the first second of our excerpts contained a single chord or pitch interval (excerpts 1, 3, 4, 7, 8, 9, 10, 17, 21) and sometimes even a single tone (excerpts 5, 6, 19). It may be argued that participants may have been able to recognize the emotion contents of stimuli as short as one second without being actually ''moved'' by such short excerpts (see Gabrielsson, 2001; Scherer & Zentner 2001, for a discussion of induced vs. perceived emotions). But even in this case, it remains remarkable that such a short duration suffices for refined emotional judgements.

The fact that these excerpts generally elicited an accurate response highlights that 1 second of music contains enough cues for an emotional reaction. Appendix B reveals that these cues may relate to structural factors, such as key and mode (major vs. minor), pitch intervals (consonance vs. dissonance), chordal disposition, orchestration, rhythm, pulsation, metre, and timbre, as well as performance features (notably amplitude envelopes). Hearing the 1 s excerpts would convince readers of the considerable importance of performers' cues. This importance explains why the location of excerpts 5, 6, 19, which contained a single tone, may have been so appropriate. Performing one event expressively, even a single note, is clearly enough to prime in listeners the musical expression of the remainder of the excerpt. The importance of performance for musical expressivity is well established (see Juslin, 2001; for a review, see Gabrielson and Lindström, 2001). It is well known that each event of a piece should be performed as a function of the musical expressivity of the context and as a function of the musical style of the piece. The constraints of performing Western classical music are such that highly expert performers follow an extremely long and intensive training. It seems likely that Western listeners have internalised, through mere exposure to Western music, the way in which these cues are usually combined to convey specific emotions. This combination is so codified in Western culture that a very short slice of expressive music could be sufficient to induce a specific emotion. Emotional responses to short musical excerpts thus presumably arise from a rapid process that consists in matching available cues found in musical structure and performance with emotional responses previously experienced from these cues. Great music lovers are indeed often emotionally engaged from the very first sound of a performance.

The last striking issue of the present study concerns the role of musical expertise. The present study confirmed that emotional responses to music do not strongly depend upon the extent of musical training (Lynchner, 1998). This finding is somewhat remarkable since the music stimuli of the present study were of great complexity and were voluntarily chosen by a music theorist to induce refined emotions. The weak difference between the two groups can be understood in the light of several current studies on music cognition that demonstrate the great ability of nonmusicians to process subtle musical structures of crucial importance in Western music (for a review, see Bigand & Poulin-Charonnat, in press). As long as the experimental task involves an implicit level of processing, nonmusicians perform similarly to musical experts exactly as they did in the present study.

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APPENDIX A
Experiment 1: 27 music excerpts used as stimuli

1. *R. Strauss. Also sprach Zarathustra, op. 30.* Long, slow, ascending melody in a major key with consonant harmonies, characterised by a warm string timbre and a full sound resulting from the arrangement of parts. Some local tensions which are immediately resolved.

2. *J.S.Bach. Violin Sonata 3, Fuga.* Long melody in a major key for solo violin, played at a moderate tempo, with a polyphonic feel. Dissonances are neutralised by great rhythmic stability and predictable patterns of voice leading.

3. *W.A.Mozart. Piano Concerto Adagio*, K 488. Theme in a minor key, played at a very slow tempo. Melancholic trochaic rhythm characterised by a large intervallic distance between sounds grouped by the left hand, and the melody in the high register of the right hand, creating avoid in the middle of the range which reinforces the desolate aspect of the theme.

4. *J. Brahms. Violin Concerto, Adagio.* Thematic exposition on the oboe of a slow, pure melodic line, built on the tonic major chord, and standing apart above a timbrally rich, sustained orchestra. Harmonic expanses of perfect major chords are spread across the orchestra. The doubling of lines serves to reinforce the fullness of sound of the whole.

5. *D. Scarlatti. Sonata A for Harpsichord*, K208. Ascending theme comprising melodic contour with a very simple rhythm, played at a slow tempo with the soft and intimate timbre of the guitar, above strongly anticipated major chord harmonies that resonate fully in the instrument.

6. *R. Schumann. Träumerei, op. 15, no. 7.* Theme with a very pure melodic contour, built on a perfect major chord, played tenderly at a slow tempo by the right hand of the piano, accompanied in the left hand by calm major chords, sometimes arpeggiated, which fill out the tessitura and whose consonance resonates fully. Softness of parallel movements a tenth apart.

7. *D, Shostakovitch. Symphony 15, Adagio.* Brass chorale on a very slow homorhythmic sequence of chords in a minor key at the bottom of the register, animated by some chromatic embellishment and melodic movement. Dark atmosphere.

8. *D. Shostakovitch. Trio 2 for piano, violin, and cello, Largo*. Long melody for violin, played at a slow tempo above low notes on the piano, to which the cello replies with false imitations that are temporally out of phase, and create strong expressive dissonances. The heartbreaking character of these dissonances is reinforced by the feeling of emptiness produced by the intervallic distance between the two parts.

9. *R. Wagner. Tristan, Act 3.* Declamation in the low register of the strings of the orchestra. Very strong harmonic tension within a minor key with on the 6th chord against a dissonant second. Slow and dilated tempo. The upper parts ascend in pitch by chromatic movement, with unresolved intervallic tensions. The absence of a bass creates a feeling of vertigo and of ascension into infinity.

10. *J. Brahms. Trio, piano, violon, and horn, mvt 2.* Repetition of a thematic rhythmic motif, above major key harmony, punctuated by brass effects, at a rapid tempo and with a very rich sound. The sonority of the French horn enriches the timbral quality of the ensemble, and the structure of the piece is reinforced by the presence of transposed harmonic progressions.

11. *F. Liszt. Les Préludes.* Powerful orchestral tutti presents consonant harmonies with a martial rhythm at a solemn tempo, proceding by movements of a third and fifth, played with full sonorities, doubled by the brass in the bass.

12. *S. Prokovief. Sonata for piano, no. 3, op. 28*. Highly agitated piano line, with aggressive attacks and wild sonorities, pounded in the left hand, developing at a rapid tempo above an irregular rhythm, with juxtaposed harmonies that are neither prepared nor resolved.

13. *L. Beethoven. Symphony 7, Vivace*. Powerful orchestral tutti develops a rhythmic ostinato doubled by the timpani, based on a consonant harmony above which a melody is constructed from the tonic major. Great timbral richness. Joy, colossal energy.

14. *L. Beethoven. Piano, Sonata 32, mvt 2.* Dynamic motif, presented at a fast tempo on a syncopated rhythm evocative of jazz, and constructed around major tonic and dominant chords. Great energy.

15. *F. Mendelssohn. Italian Symphony, mvt 1*. Long melodic line stated by the violins with vigour and lightness. Major key harmonies built on tonic, dominant and subdominant chords, played at a high tempo with a pulsating rhythm, supported by a semiquaver ostinato in the rest of the orchestra.

16. *F. Chopin Prelude 22.* Motif in the low register of the piano repeated obsessively and characterised by pounding octaves in the left hand, dissonant harmonies, and accompanied in the right hand by a panting rhythm, accentuating the weak part of the beat, and breaking up the violent and hopeless discourse of the left hand.

17. *F. Liszt. Tasso Lamento & Triomfo.* Powerful orchestral line develops tense minor harmonies on a choppy rhythm and at a rapid tempo, supported by the entry of the percussion.

18. *R. Strauss. Tod and Verklärung, 7'-7'30.* Powerful orchestral line, presenting dissonant harmony above a long pedal, and unresolved chromatic movements starting from the extremes of the register and progressing in contrary motion to result in an out of phase rhythmic pounding in the bass drum and brass.

19. *J. S Bach Violin Sonata.* Minor key melodic theme at a moderate tempo. Great metric stability, based on part imitation and dissonances which are always resolved.

20. *W.-F. Bach. Duetto for two flutes in F, Lamentabile.* Repeated melodic figures built on the tonic major chord, containing tensions and dissonances that are not always resolved immediately. Slow tempo and very soft timbre.

21. *J. Haydn. Symphony Bdur, Hob I 105, Andante.* Thematic motif presented in thirds on the violin and bassoon, played at a moderate tempo, centred on notes from the tonic and dominant major chords.

22. *W.-F. Bach. Duetto for two flutes in G, Allegro.* Duo of flutes imitate each other over broken arpeggios of tonic and dominant major chords. Very soft timbre though a leaping rhythm and a lively tempo.

23. *F. Schubert. Valse no. 3, op. 50, D779.* Dynamic melodic motif played in the top register of the piano. Regular waltz rhythm and a lively tempo over simple tonic/dominant harmonies.

24. *I. Stravinsky. Petrouchka.* Repeated melodic pattern of ascending 4ths presented with great momentum and harshness by the flute, to which the strings reply in modal harmonies, all above the incessant swarming of the orchestra, evoking a jubilant crowd.

25. *A. Schoenberg. Erwartung*. Dissonant rhythmic and melodic ostinato in the strings, flutes and bassoons dominated by the strident entry of the piccolo, clarinet, and muted trumpet. Acceleration of the already lively tempo, and large crescendo culminating in a violent punctuation from the orchestra.

26. *D. Shostakovitch. Trio 2 for violin, cello, and piano, moderato.* Series of snatched intervals in the strings, very dissonant with a grating sonority, punctuated over an agitated and irregular rhythm by tense chords in the piano. Continued by a dissonant chromatic ascent in the violin and cello over a harmonic suspension in the high register of the piano.

27. *F. Liszt. Totentanz.* Aggressive march; pounding dissonant diminished seventh chords in the low register of the piano, above which the *dies irae* theme is presented, strongly out of metrical phase, supported by the bass drum.

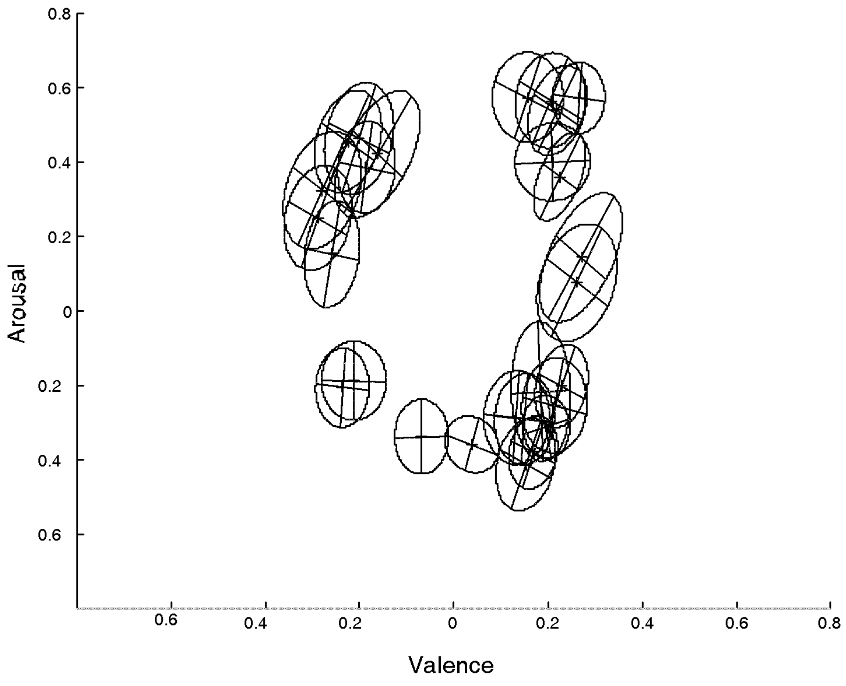

Diagram 1. Bootstrap analysis of Experiment 1

APPENDIX B
Experiment 2: Features in the first second of the 27 music excerpts

1. *R. Strauss. Also sprach Zarathustra.* Long sustained texture in the strings with the fifth apparent, suggesting the beginning of a very slow melodic movement. Ambiguous emotional valence.

2. *J. S. Bach. Violin Sonata 3, Fuga.* Single high note repeated three times giving a bouncing character marked by differences of attack and timbre to create a metrical pulsation.

3. *W. A. Mozart. Piano Concerto, Adagio,* K 488. A high, perfect minor chord with a soft attack and wide spacing between the third and the tonic. The long resonance heralds a very slow movement.

4. *J. Brahms. Violin Concerto, Adagio.* A perfect major chord played by the orchestra over which a high oboe note stands apart. This is ''sung'' and the attack indicates the start of a long, slow, and serene melody.

5. *D. Scarlatti, Sonata A for Harpsichord*, K208. A single guitar note played softly and with a sonorous resonance in the middle of the tessitura, foreshadowing a broad melodic movement with a regular rhythm.

6. *R. Schumann. Träumerei, op. 15, no. 7.* A single piano note in the middle high register, with a very soft attack and with full resonance predicting the start of a very slow movement.

7. *D. Shostakovitch. Symphonie 15, Adagio.* An interval of a minor third held by the brass in a dark, low register, with an amplitude enveloppe that anticipates a slow movement.

8. *D. Shostakovitch, trio 2 for piano, violin, and cello, Largo*. A single, held, dissonant harmony resonant in the low register of the strings, with an amplitude enveloppe that foreshadows a long musical phrase.

9. *R. Wagner. Tristan, Act 3.* Declamation of a minor chord in the low register of the strings of the orchestra.

10. *J. Brahms. Trio, piano, violin and horn, mvt 2.* A strident major chord, with the arrangement of the parts and the timbre of the French horn confering a very full sonority.

11. *F. Liszt. Poeme symphonique.* Powerful orchestral tutti on a major chord, with a triumphant character marked by the strong trumpet presence, and an amplitude envelope which grows dramatically.

12. *S. Prokovief. Sonata for piano, no. 3, op. 28*. Complex melodic line of nine notes in contrary motion at a lively tempo, marked by aggressive attacks and many dissonances.

13. *L. Beethoven. Symphony. 7, Vivace.* Strong ascending melodic motif in the strings leading towards a powerful orchestral tutti on a perfect major chord.

14. *L. Beethoven. Piano, Sonata 32, mvt 2.* Energetic melodic line of seven arpeggiated notes of a major chord in a repeated compound rhythm announcing a rapid metrical beat.

15. *F. Mendelssohn. Italian Symphony, mvt 1*. Strong major third motif played in the violins with accents that indicate a rapid rhythmic pulse, confirmed by the semiquaver ostinato played on a tonic chord by the rest of the orchestra.

16. *F. Chopin. Prelude 22.* Melody of four piano notes centred on a minor third, strengthened in the low register of the piano. Strong attack on a rhythm that indicates a fast tempo.

17. *F. Liszt. Tasso Lamento & Triomfo.* Biting explosion of an orchestral tutti on a dissonant chord, strengthened by the percussion in a clearly romantic style of orchestration.

18. *R. Strauss. Tod and Verklärung, 7'-7'30.* Two minor key chords played with force in the low registers of the orchestra, the first reinforced by low percussion instruments and the second by a bright brass entry.

19. *J. S Bach. Violin Sonata.* A single high note on the violin, supported but with little vibrato and a very bright timbre, whose amplitude envelope announces a determined musical gesture.

20. *W.-F. Bach. Duetto for two flutes in F, Lamentabile.* Two detached flute notes with slight sustain, and a very soft timbre. Short long rhythm announces a moderate beat and rhythm.

21. *J. Haydn. Symphony Bdur, Hob I 105, Andante.* Minor third interval from a major chord, played by the violin and bassoon, which gives a soft, pastoral feel. The dynamic evolution announces a moderate tempo.

22. *W.-F. Bach. Duetto for two flutes in G, Allegro*. Five arpeggiated flute notes from a perfect major chord with a soft timbre and a swift, regular metre.

23. *F. Schubert. Valse no. 3, op. 50, D779.* Five high piano notes pick out a perfect major chord in a triple rhythm, whose articulation indicates the style and character of the rest of the piece.

24. *I. Stravinsky. Petrouchka.* Four high flute notes, in ascending fourths, separate above a dynamic string texture with accents pointing to a fast rhythmic pulse.

25 *A. Schoenberg. Erwartung.* Orchestral ostinato on 5 notes marks a swift tempo, played with shortened attack and resonance to create a breathless character with very tense pitch intervals.

26. *D. Shostakovitch. Trio 2 for violin, cello, and piano, moderato.* Three snatched intervals in the strings, containing many high and very dissonant harmonics, separating themselves from a low piano note with a rapid tempo.

27. *F. Liszt. Totentanz.* Aggressive march played in the low register of the piano, in a minor harmony, with a mechanical character indicating a very stable, rapid tempo.