Is Vivaldi smooth and takete? Non verbal sensory scales for describing music qualities*

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Abstract

Studies on the perception of music qualities (such as induced or perceived emotions, performance styles, or timbre nuances) make a large use of verbal descriptors. Although many authors noted that particular music qualities can hardly be described by means of verbal labels, few studies have tried alternatives. This paper aims at exploring the use of non verbal sensory scales, in order to represent different perceived qualities in Western classical music. Musically trained and untrained listeners were required to listen to 6 musical excerpts in major key and to evaluate them from a sensorial and semantic point of view (Experiment 1). The same design (Experiment 2) was conducted using musically trained and untrained listeners who were required to listen to 6 musical excerpts in minor key. The overall findings indicate that subjects' ratings on non verbal sensory scales are consistent throughout and the results support the hypothesis that sensory scales can convey some specific sensations that cannot be described verbally, offering interesting insights to deepen our knowledge on the relationship between music and other sensorial experiences. Such research can foster interesting applications in the field of music information retrieval and timbre spaces explorations together with experiments applied to different musical cultures and contexts.

1 Introduction

Music is a multifaceted reality covering an important role in many aspects of our life. The power of music to arouse in the listener a rich set of sensations, such as images, feelings or emotions, can have many applications in everyday life, such as entertainment (Zanolla et al., 2013), rehabilitation (Rosati et al., 2013) and sport training. Digital technologies and new playback devices (e.g. mobile devices) have rapidly changed the way we listen to music: on one hand, one can access to a huge amount of musical contents in any moment of the day and during almost any activity, including work, travel, eating, run, swimming, sleeping; on the other hand, mobile devices are equipped with or linked to increasingly sophisticated sensors, that can track human actions (such as arm movements and pace rate) and bodily responses to those actions (e.g. heart rate, skin conductance) and all this information can be instantaneously shared through social networks.

Traditionally, studies on music qualities such as induced or perceived emotions, performance styles, or timbre nuances make a large use of verbal labels. The most popular quantitative experimental method in this field is the semantic differential (Osgood et al., 1957), an instrument for measuring the connotative meaning of music through bipolar rating scales.

Given the recent scenario, where music playback devices allow us to interact with music by means of touch/actions/gestures, are verbal descriptions alone suitable to represent the multiform qualities of

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music? Can we find non-verbally-mediated forms of representation based on an action paradigm? Can we discover forms of association that can help the understanding of music hidden qualities? How takete is Vivaldi and how blue is Mozart?

Starting from the well-known semantic differential method, this paper aims to explore the use of non-verbal sensory scales to study different perceived qualities in Western classical music. The broad hypothesis is that both musically trained and untrained subjects are able to consistently differentiate music excerpts along sensory qualities such as a piece of rough paper or a hot object. Moreover, we aim to compare non-verbal sensory scales with verbal scales, under the hypothesis that non-verbal sensory scales can provide a different representation of musical qualities to the traditional semantic differential method.

After an overview of previous studies investigating music from a non-verbal point of view (Sect. 2 and 3), we present two experiments (Sect. 4 and 5) that use two different set of musical stimuli and the same set of verbal and non-verbal sensory scales. The comparison on the main results of the two experiments will be finally discussed in Sect. 6.

2 Background

2.1 Music and language

The idea of music as a language has been widely debated in past years, (see e.g. Clark (1982)). Though music lacks the specificity of natural language in terms of semantic meaning (Patel, 2007), neurological studies have recently showed that the brain seems to "see" music as a language, in the sense that the mechanisms underlying syntactic processing are shared between music and language (Patel, 2003). Such syntactic processes are instantiated in overlapping frontal brain areas that apply over different domain-specific syntactic representations in posterior brain regions. Nevertheless, lesion and neuroimaging studies point out that some musical activities like singing, memorisation of music, and sight-reading are functionally and neuroanatomically dissociable from analogous activities that involve speech (Peretz and Morais, 1989). According to Peretz and Hyde (2003), some processing components appear to be genuinely specialized for music, while other components could be involved in the conjoint processing of music and speech.

In any case, there are many evidences that music expresses something, in the sense that groups of more or less culturally homogeneous subjects have similar experiences when they listen to the same music piece. Music has even been described as the "language of emotions" by some authors (Cooke, 1959) and many studies, investigating the relationship between music and emotions, have shown that it is possible to correlate the listeners' main appraisal categories and the acoustic parameters, even though there is still much debate on the distinction between perceived and induced emotions (Gabrielsson, 2002), (Schubert, 2013). According to the functionalist approach, emotional expression in music is partly based on a code for vocal expression of basic emotion categories; music performance uses largely the same emotion-specific patterns of acoustic cues as does vocal expression during verbal language production (Juslin and Laukka, 2003). Music performers communicate emotions to listeners by exploiting an acoustic code that derives from innate brain programs for vocal expression of emotions.

But what music expresses is not limited to emotions. In the field of music expressiveness, we note that much of what is said about music is actually about performances of pieces. If we reflect on the way in which scores are thought, analysed and discussed, we can realize how often musicologists and music theorists treat the composer as if s/he were the principal agent of meaning. "Schubert lingers affectively on this glimpse of bucolic happiness, though without slackening the pace of the song" (Kramer, 2003). "Beethoven hurls forth the P0 (primary theme) module, Allegro vivace, in a set of three impetuous, downward-cast precipitations" (Hepokoski, 2010). In these two examples the composer is treated as if he were also the performer. The writer tells us how the piece should sound - "should" because the conception is attributed to the composer as performer. According to Leech-Wilkinson (2012), as soon as we start thinking about the relationships between notes, we have to imagine those notes sounding and our linguistic translation does not refer to an abstract musical performance, but to a particular performance style, the performance style current around us (Leech-Wilkinson and Prior, 2013).

Linguistic symbols communicated from sender to receiver do not represent involvement with music in a direct way, since they cannot render that sense of timelessness and loss of feelings of self-consciousness that a music flow experience can bring. Music does not allow the discursive, reciprocal communication of meaning, but rather an immediate and ineffable communication (Jankélévitch and Abbate, 2003). Music, said Debussy, is made for that which cannot be expressed (Siohan, 1959). “The truth we cannot speak about, we must sing, we must say it in music” (Berio, 2006).

2.2 Music and action

According to Leman (2008), music perception is rooted in action. People try to be involved with music, because this involvement permits an experience of behavioural resonance with physical energy. Being aware of the state of the environment in which music occurs can engage the mind in thinking and reasoning processes that may break the magic spell of being entrained. The measurement of musical involvement by introspection is very difficult, since, as soon as direct involvement is evaluated and mentally represented in a conscious way, it seems to disappear.

Some experimental designs have been proposed with the aim of studying the perceived qualities of music without following the semantic differential approach. De Poli et al. (2009) carried out experiments using two sets of musical excerpts, with simple and complex musical structure respectively, and three haptic reaction forces, provided by means of a force feedback device, which simulate the mechanic concepts of friction, elasticity and inertia (FEI). Participants were asked to associate each musical piece to one of the three reaction forces. The results showed that subjects are able to consistently relate the musical excerpts with the reaction forces, even if the FEI metaphor seems to be more suitable for describing expressive cues in simple musical excerpts, where the expressive content is mainly related to performance cues, than in complex musical stimuli, where musical structure is more relevant.

Amelynck et al. (2012) asked the subjects to express the affective character of a set of musical fragments by arm movements, while listening to the fragments. The subjects’ arm motion was captured using a wireless handheld device equipped with 3D inertial sensors. The results show that human subjects are generally capable of expressing and recognizing affective qualities in music from arm gestures.

Barten (1998) identified the effectiveness of metaphorical verbal instructions for teaching the physical skills of music performance. Often, instructors use imagery of movement, such as an object travelling through the air and falling to the ground, to bring attention to the motional aspects of music, perhaps invoking musical concepts of “phrase” and “line”. This metaphoric language is particularly effective in improving the student’s performance, since it is conveyed through a particular vocal inflection, facial expression, gesture, posture, rendering the linguistic expression more vivid and emotionally loaded.

2.3 Crossmodal correspondences

The characteristic of music of eliciting a rich number of often shared sensations and images may be based on crossmodal correspondences which can be interpreted as intrinsic attributes of our perceptual system’s organization (Marks, 1978). Many studies investigated the relationship between music and colours, tastes, vision and odours, proving that people exhibit consistent crossmodal responses in different sensory modalities. In particular, Martino and Marks (2001) introduce the two concepts of strong and weak synaesthesia, arguing that these two phenomena may share similar neural mechanisms, probably involving sensory and semantic areas of the brain. Strong synaesthesia refers to a vivid percept in one sensory modality induced by stimulation in another, while weak synaesthesia refers to a correspondence expressed through language, perceptual similarity and perceptual interactions between different sensory experiences. According to Spence (2011), crossmodal correspondences between different combinations of modal and amodal features need to be considered alongside semantic, spatiotemporal, developmental and affective dimensions, since such correspondences are mediated not only by innate factors, but also by experience and statistical factors. In particular, Spence distinguishes between structural, statistical and semantic correspondences and hypothesize that structural correspondences may bear fruitful comparison with synaesthesia, while other kinds of correspondence may need a different theoretical interpretation. As regards the neural substrates underlying crossmodal correspondences, polysensory areas in the temporal cortex have been shown to respond more vigorously to crossmodally congruent pairings of simultaneously presented auditory and visual action stimuli (Beauchamp et al., 2004). Moreover, damage to the angular gyrus can interfere with a person's ability to match stimuli crossmodally as in the bouba/kiki test (Ramachandran and Hubbard, 2001).

Ward et al. (2006) studied a group of synaesthetes reporting colour sensations in response to music and other sounds. Her experiment showed that synaesthetes choose more precise colours and are more internally consistent in their choice of colours given a set of sounds of varying pitch, timbre and composition (single notes or dyads) relative to a control group. In spite of this difference, both controls and synaesthetes appear to use the same heuristics for matching between auditory and visual domains (e.g. pitch to lightness). Overall, the results support the conclusion that this form of synaesthesia recruits some of the same mechanisms used in normal crossmodal perception rather than using direct, privileged pathways between unimodal auditory and unimodal visual areas that are absent in most other adults.

Crisinel and Spence (2010) performed an experiment investigating crossmodal correspondences in synaesthetes and nonsynesthetes through explicit matching of sounds of varying pitch to a range of tastes/flavours. In addition, participants also chose the type of musical instrument most appropriate for each taste/flavour. The association of sweet and sour tastes to high-pitched notes was confirmed. By contrast, umami and bitter tastes were preferentially matched to low-pitched notes. The choice of musical instrument was primarily driven by a matching of the hedonic value and familiarity of the two types of stimuli.

Belkin et al. (1997) investigated the relationship of certain odours (in particular, those that are commonly used in perfumery) to the pitch of a tone. The stimuli were drawn from several fragrance categories (e.g. floral, citrus, woody, earthy) and included essential oils extracted from botanical sources as well as synthetic aroma compounds. Discussing the results of the experiment, Belkin hypothesised that stimulus intensity and pleasantness cannot account for the matching of odours and sounds, since the relevant perceptual feature appears to be some aspect (or aspects) of odour-quality coding. According to Belkin, subjects could have based their pitch matches along such putative olfactory dimensions as dull-aromatic, heavy-light, bright-dark, or hard-soft.

Ramachandran and Hubbard (2001), replicating Köhler's experiments (Köhler, 1929) with maluma and takete using the words "kiki" and "bouba", suggested that the human brain somehow attaches abstract meanings to the shapes and sounds in a consistent way. They hypothesise that the kiki/bouba effect has implications for the evolution of language, because it suggests that the naming of objects is not completely arbitrary.

De Götzen (2014) experimented the association of maluma and takete with two sound movements in space, proving that, also in this particular case, the quality of the movement is easily associated to the quality of words.

All these studies show that crossmodal correspondences exist between a variety of auditory, visual, gustatory, haptic and tactile stimuli. In this regard, we believe that sensory scales can represent a suitable tool to measure, describe and directly access such crossmodal similarities in response to a piece of music.

3 Metodological issues

3.1 Cluster analysis of music qualities

In order to study how the affective qualities of music are perceived in the absence of verbal descriptions, Bigand et al. (2005) proposed an experimental setup that does not use verbal labels to describe differences between the stimuli: musically trained and untrained listeners were asked to listen to 27 musical excerpts taken from the Western classical repertoire and to freely group those conveying similar subjective emotions. By means of cluster analysis and multidimensional scaling (MDS), the musical excerpts resulted to be grouped into four main clusters, interpreted as high arousal and high valence (HAHV); high arousal and low valence (HALV); low arousal and high valence (LAHV); low arousal and low valence (LALV). Following this approach,subjects could choose to divide the stimuli into as many groups as they wanted.

A variant of this approach consists in asking subjects to associate each music piece to one of n representative music stimuli, called *attractors* (Mion et al., 2010). By means of attractors, subject are induced to focused on particular aspects of music qualities, without using verbal label. E.g., Mion et al. (2010) used three attractors, obtained asking a musician to play a major scales with three different expressive intentions, i.e. three different performance styles. Asking the subject to associate a set of music excerpts with one on the three attractors, they were induced to focus on the performance aspects of the music excerpts.

Cluster analysis can be also carried out starting from the acoustic analysis of the music excerpts. Mion and De Poli (2008) used machine learning techniques to select the audio features that are most relevant for the recognition of different music qualities both in the affective (valence-arousal) and sensorial (kinematics-energy) spaces. The analysis of the feature space revealed a structure into three clusters, interpreted as hard/heavy/angry, light/happy, and sad/calm/soft respectively.

Music composers know very well that the music mode and the performance tempo are related to the affective properties of music. Traditionally, the minor mode has been attributed to feelings of grief and melancholy whereas the major mode to feelings of joy and happiness (Hevner, 1936) (Kastner and Crowder, 1990), (Gerardi and Gerken, 1995). In order to reduce the relevant influence of modality and tempo, Rodà et al. (2014) planned two experiments imposing some constraints on the musical features, namely modality and tempo, of the stimuli. In particular, the first experiment used music excerpts in major-mode only, whereas the second one excerpts in major-mode and performed at 104 bpm. Following an experimental method based on free grouping (Bigand et al., 2005), the authors showed that participants grouped the stimuli in a consistent way, structuring them into three main clusters, interpreted as low arousal (LA), high arousal and low potency (HA-LP), high arousal and high potency (HA-HP) respectively. Preliminary experiments showed that this three-cluster structure can be also obtained with minor-mode-only excerpts.

3.2 Non-verbal sensory scales

The use of linguistic labels is one of the most complex problems of the studies investigating the emotional aspects of music. Musical emotions are so undetermined that it is difficult to render them through words, since the determinedness of language causes an inevitable loss in richness of meanings. The use of verbal labels can encourage participants to simplify what they actually experience (Scherer, 1994) and it is still uncertain if research based on the recording of electrophysiological responses to musical stimuli (Khalfa et al., 2002; Krumhansl, 1997) can faithfully account for the subtlety of musical emotions.

Some perceptual experiences cannot be expressed by means of an accurate, reliable language (lexicon) and this fact is proved by the high interindividual variability in the attempts to describe them. Particular touch experiences, such as variations of springiness and slipperiness have no correspondent verbal descriptors, even if their perceptual understanding is very simple (Guest et al., 2011).

In order to establish a correspondence between concepts from disparate domains of knowledge, we decided to exploit cross-domain mappings by means of metaphoric association. According to psycholinguistic theories (Bowdle and Gentner, 2005), highly conventional metaphors are processed without any active mapping from the source to the target domain (e.g. from space to pitch) since they are interpreted as directly as literal language.

Sensory scales were first introduced by Da Pos and Pietto (2010) with the aim of substituting Osgood's verbal scales with sensory ones. For instance, instead of asking the observer where he/she would have placed his/her light impression in the continuum between 'warm and cold' expressed by words, they made the observer feel his/her hands cool or warm by plunging them in cold and warm water. The results obtained confirmed the hypothesis that sensory scales greatly improve the efficiency of the semantic differential in enlightening the impact that perceived objects and events determine in the human mind

In our experiments we asked participants to evaluate their musical experience from a subjective sensorial point of view. Seven non verbal sensory scales (visual, auditory, tactile, haptic and gustative) were presented in random sequence in order to stimulate a quasi-synaesthesic response. Participants were confronted with the following scales: maluma/takete, blue/orange, hard/soft, smooth/rough, bitter/sweet, heavy/ light, cold/warm previously tested in an experiment on colour perception (Da Pos et al., 2013b). In this case the aim of the researchers was the study of different reactions to normal or iridescent colours and it resulted that evaluations in all scales, sensory and semantic, significantly discriminated normal from changeable colours.

Another study (Da Pos and Pietto, 2010) on unique hues led to the discrimination of four characteristic factors: one including the three verbal scales typical of Osgood's findings, one including the warm/cold scale, one characterized by the sensory opposition of dissonant, aloud, and orange against consonant, faint, and turquoise and the last including the glass-sandpaper scale, and the light-heavy scale dealing with the sensation of smoothness given by the light sources. These two studies confirmed the hypothesis that the sensory scales used in the evaluation of light sources can show up relevant qualitative aspects otherwise hidden.

As regards the semantic analysis, we decided to rely upon the semantic differential, a type of rating scale designed to measure the connotative meaning of objects, events, and concepts ideated by Osgood and his colleagues (Osgood et al., 1957). Ratings on bipolar adjective scales tend to be correlated, and three basic dimensions of response account for most of the co-variation in ratings. The three dimensions, which have been labeled Evaluation, Potency, and Activity have been verified and replicated in an impressive variety of studies. Evaluation can be matched to the adjective pair "desirable-undesirable". The "gentle-violent" adjective pair defines the potency factor. Adjective pair "active-passive" defines the activity factor. These three dimensions of affective meaning were found to be cross-cultural universals in a study of dozens of cultures. Semantic differential technique is a multivariate approach to affect measurement. It is also a generalized approach, applicable to any concept or stimulus, and thus it permits comparisons of affective reactions on widely disparate topics.

4 Experiment 1

4.1 Participants

Twenty participants were recruited on a voluntary basis, of which 12 were musicians (age range 17-25, mean age 21.4; 8 women and 4 men) and 8 were non-musicians (age range 24-68, mean age 42; 4 women and 4 men). A questionnaire was administered to determine the participants' musical background and experience, including listing the instruments played and number of years trained in each instrument.

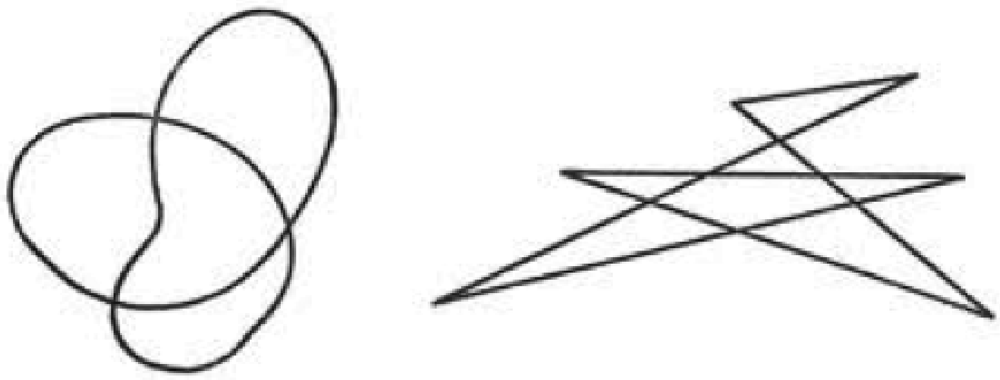

Figure 1: The two forms named maluma (on the left) and takete (on the right) Köhler (1929).

4.2 Stimuli

The musical excerpts were selected starting from two previous works by Bigand et al. (2005) and Rodà et al. (2014), in which experiments were conducted to study the clustering of the affective qualities of music (see Sect 3.1). For the present study, six music pieces, representing the three main clusters of Rodà et al. (2014), two pieces for each cluster, were chosen. All the selected stimuli were in a major tonality. Each excerpt had a duration of about 30 seconds. A list of the stimuli is reported in Appendix A.

4.3 Materials

We prepared the following material:

- maluma - takete Köhler (1929), computer visualization of the two visual forms (cm 4,3 x 4, 3);
- blue - orange, the computer display of the two colors (NCS notation: S 2055-B10G, S 1080-Y70R, cm 4,3 x 4, 3);
- hard - soft, a piece of wood of cylindrical shape and a cylinder of polystyrene foam (16x3x3 cm; 16x6x6 cm);
- smooth - rough, N 1200 and N 30 sandpapers (cm 15x10,5);
- bitter - sweet: a bitter substance (Zefirus Calma Plant, 2 drops in a small cup) and water with sugar (1 teaspoon of sugar in a small cup);
- heavy - light: a dark plastic bottle full of liquid (500 ml) and the same bottle without liquid (5 g). The dull color of the bottle didn't allow participants to distinguish the full from the empty bottle;
- cold - warm: one cup of cold water and one cup of warm water (temperature: $5°$ and $40°$).

4.4 Procedure

The sound files were represented on the computer screen by small icons with the number of the musical excerpts. Participants listened to the excerpt once (30 seconds), but they had the possibility to listen to the stimuli as many times as they wanted. To avoid order effects, sensory and semantic scales were administered randomly. The experiment consisted in expressing a subjective judgment on the characteristics of the excerpt heard by placing the indicator inside the slider at the point that was considered representative of the association strength either with the sensations on which the listener was focused, or with the meaning of the verbal terms proposed. The slider had no visual references (numbers or internal divisions) apart from the position of minimum and maximum. The computer program transposed and registered the chosen position.

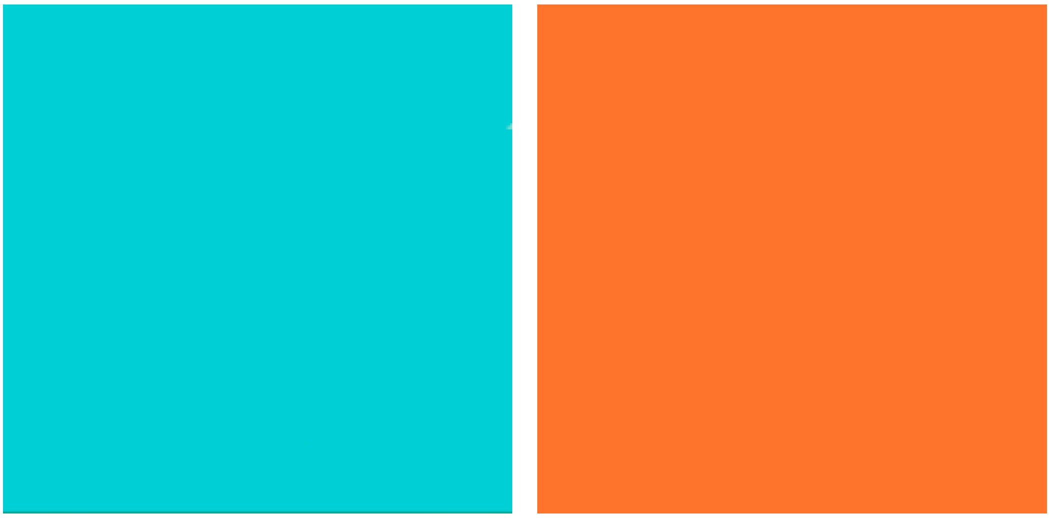

Figure 2: The two colours that constitute the second sensory scale.

After listening to each excerpt, participants could express their evaluations along the 20 scales (7 sensory and 13 verbal)and register them by clicking on a bar put under the slider. Once the subjective rate was confirmed, participants could express the following one.

The average duration of the experiment was 20-25 minutes, but, interestingly enough, musicians tended to complete the task in a longer time. Probably they weighed their answers in a more careful way, since the musical excerpts stirred emotions connected to the autobiographical memory, thus activating more complex associations. To evaluate the expressive characteristics of the excerpts, a new version of Osgood semantic differential was used Da Pos et al. (2013a). We used thirteen verbal scales corresponding to Osgood's three main factors: activity (1, 5, 10, 12) evaluation (2, 4, 6, 7, 8, 9), and power (3, 11, 13).

- Active - Passive
- Boring - Interesting
- Slow - Fast
- Superficial - Deep
- Tense - Relaxed
- Masculine - Feminine
- Clear - Confused
- Undesirable - Desirable
- Brilliant - Dark
- Simple - Complex
- Shaken - Calm
- Intimate - Open air
- Gentle - Violent

4.5 Results

Initially, the average scores for the musicians and the non-musicians subjects were separately calculated. The two sets of values presented a high correlation value ($r(118) = 0.87$, $p < .001$, where r is the Pearson's correlation coefficient and p-value is computed using algorithm AS 89 Best and Roberts (1975)), implying a high agreement between musicians and non-musicians. Then, the following results includes the responses of both groups.

A multivariate analysis of variance (MANOVA) was carried out considering the musical excerpts as independent variable and the 20 scales (sensory and verbal) as dependent variable. A significant multivariate main effect was found for the musical excerpts (Wilks'$\lambda = .013$, $F(100, 375) = 5.39$, $p < .001$, $\eta^2{}_p = .581$).

The Cronbach's α statistic has been computed to test the inter-subjects reliability. Results show that subjects are able to rate music on the seven non-verbal sensory scales in a highly consistent way ($\alpha = 0.90$), i.e. subjects are able to recognize the sensorial differences of the non verbal scales and to associate them with musical stimuli in a meaningful way, although this value is slightly lower than the Cronbach's statistic computed for the verbal scales only ($\alpha = 0.96$) and for all (both verbal and sensory) the scales ($\alpha = 0.94$).

Figure 4.5 represents the average subjective evaluations on each sensory scale; musical excerpts are reported along the x-axis and are identified with the number listed in Appendix A. In addition, error bars are displayed (standard error of means) for each average value. It can be noted that the musical stimuli are judged very differently on some scales (e.g. maluma-takete), while the differences are less marked on other ones (e.g. hard-soft).

An ANOVA analysis was carried out in order to emphasize the average values that are significantly different. Table 1 shows the significance levels (p-value) of the differences between each pairs of musical excerpts. P-values are corrected by means of False Discovery Rate (FDR) using the Benjamini-Hochberg procedure Benjamini and Hochberg (1995), which relies on the p-values being uniformly distributed under the null hypothesis. Accordingly, the procedure consists of sorting the p-values in ascending order, and then dividing each observed p-value by its percentile rank to get an estimated FDR. Stimuli 1 and 4 share the quality "maluma", while 2, 3, 5, 6 belong to the category "takete". Brahms' violin concerto (1) and Mozart's flute concerto (4) were judged significantly different from all the other excerpts. It's interesting to notice that the pairs of stimuli discriminated by the scale maluma/takete are the same differentiated by the scale light/ heavy. We can hypothesize that the listening of the stimuli aroused in participants an association between maluma and lightness. Examining the research literature, we didn't find a similar association of maluma and lightness intended as a haptic sensation. Nevertheless, Janković et al. (2005) analysed the relationship of physical characteristics of visual patterns with consonant types, asking participants to produce pseudo-words corresponding to presented monochromatic abstract visual patterns. Takete-like figures were characterised by sharp and dark patterns while maluma-like figures were associated to oval, light, luminous figures. The sensory scales blue/orange and soft/hard don't convey any significant result; Mozart and Brahms are considered the bluest and the softest stimuli, but the results don't allow us to discriminate between couples of excerpts. The scale smooth/rough enucleates excerpt 6 as the roughest. Brahms' horn trio (6) significantly differs from excerpts 1, 2, 4, 5. Also Bizet (3) is felt rough enough, since it differs significantly from 1, 2 and 4. The scale sweet/bitter is characterized by results very similar to the previous one. Brahms and Bizet are significantly different from stimuli 1 and 4. The sweetest excerpt is Mozart and it differs significantly from stimuli 2, 3 and 6. "The sweet taste of maluma" investigated by Crisinel et al. (2012) is confirmed also in our experiment, since both Brahms's violin concerto and Mozart's flute concerto are significantly characterised by these two qualities. Also in the scale warm/cold, Brahms and Mozart are considered the warmest pieces, since they differ significantly from every other excerpt. Other significant results regard stimulus 6, which differs significantly from all the other excerpts, since it is considered the coldest.

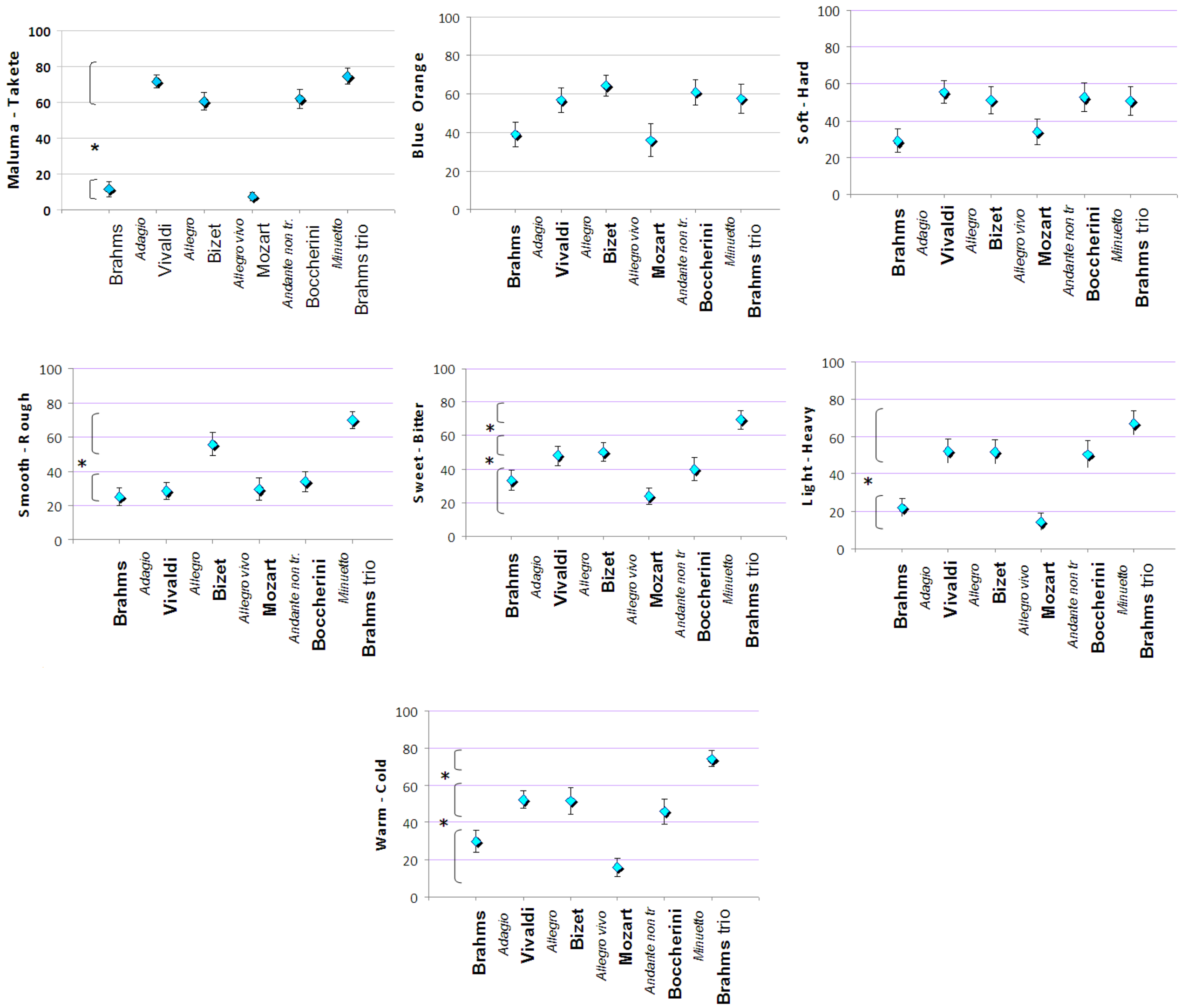

Figure 3: The average scores obtained by the six musical excerpts of Experiment 1 on the seven sensory scales. Bars indicate the standard error.

5 Experiment 2

5.1 Participants

Participants, recruited on a voluntary basis and different from the ones of the previous experiment, were 25, of which 10 musicians (age range 23-47, mean age 37.2; 3 women and 7 men) and 15 non-musicians (age range 24-77, mean age 56.1; 10 women and 5 men).

5.2 Stimuli

Six stimuli were chosen from the Western classical repertoire. Unlike the first experiment, all the selected stimuli were in a minor tonality. The six stimuli represent the three main clusters of Rodà et al. (2014), two pieces for each cluster. Four of six excerpts were also used in (Bigand et al., 2005). Each excerpt had a duration of about 30 seconds; a list of the stimuli is reported in AppendixA.

Table 1: Significance p values with FDR correction of the differences between pairs of excerpts of Experiment 1. Blank cells mean $p > .05$

	Ma/Ta	Bl/Or	Ha/So	Sm/Ro	Bi/Sw	He/Li	Co/Wa
1-2	<.001					.002	.009
1-3	<.001			.005	.029	.001	.018
1-4							.019
1-5	<.001					.010	.072
1-6	<.001			<.001	.003	<.001	<.001
2-3				.013			
2-4	<.001				.032	.001	<.001
2-5							
2-6				<.001	.037		.005
3-4	<.001			.020	.003	.001	<.001
3-5							
3-6					.038		.020
4-5	<.001					.003	.004
4-6	<.001			<.001	<.001	<.001	<.001
5-6				<.001	.023		.016

5.3 Materials and procedure

Materials and procedure are the same of Experiment 1.

5.4 Results

The average scores separately computed for the musicians and the non-musicians subjects present a high correlation value ($r(118) = 0.86$, $p < .001$, where r is the Pearson's correlation coefficient and p-value is computed using algorithm AS 89 Best and Roberts (1975)), implying a high agreement between musicians and non-musicians. Then, the following results include the responses of both groups.

A multivariate analysis of variance (MANOVA) was carried out considering the musical excerpts as independent variable and the 20 scales (sensory and verbal) as dependent variable. A significant multivariate main effect was found for the musical excerpts (Wilks' $\lambda = .001$, $F(100, 497.39) = 15.51$, $p < .001$, ${\eta^2}_p = .749$). The Cronbach's α statistic shows that subjects of Experiment 2 rated the musical excerpts on the seven non-verbal sensory scales in a highly consistent way ($\alpha = 0.90$), as for Experiment 1, a value that is slightly lower than the Cronbach's statistic computed for the verbal scales only ($\alpha = 0.95$) and for all (both verbal and sensory) the scales ($\alpha = 0.93$).

Figure 5.4 represents the average subjective evaluations on the scale indicated for each musical excerpt examined. In addition, error bars are displayed (standard error of means).

Table 2 shows the significance levels (p) of the differences between pairs of tracks. Two couples of excerpts are significantly differentiated in every sensory scale (3-5; 4-5). This means that Bach's Badinerie (5) is felt as juxtaposed both to Chopin's Prelude (3) and to Liszt's Tasso (4) and these pairs of stimuli are seen as opposites. Another interesting juxtaposition regards excerpts 1 and 3, which significantly differ in almost every sensory scale except the cold/warm scale. The sensory scale maluma/takete significantly differentiates excerpt 3 (Chopin) from 1 (Mozart), 2 (Wagner), 5 (Bach) and 6 (Rossini). This implies that Chopin's Prelude is felt as the sharpest excerpt and this is probably due to the particularly percussive style chosen by the pianist. Also excerpt 4 (Liszt) and 5 (Bach) are significantly differentiated by the sensory scale maluma/takete. As regards the sensory scale blue/orange, it is interesting to notice how Mozart (1) and Bach (5) are considered the bluest excerpts. Mozart significantly differs from stimuli 2, 3, 4 and 6, while Bach significantly differs from 3 and 4. The scale hard/soft particularly discriminates stimulus 5 (Bach). This excerpt is considered the softest one, since it differs significantly from every other stimulus.

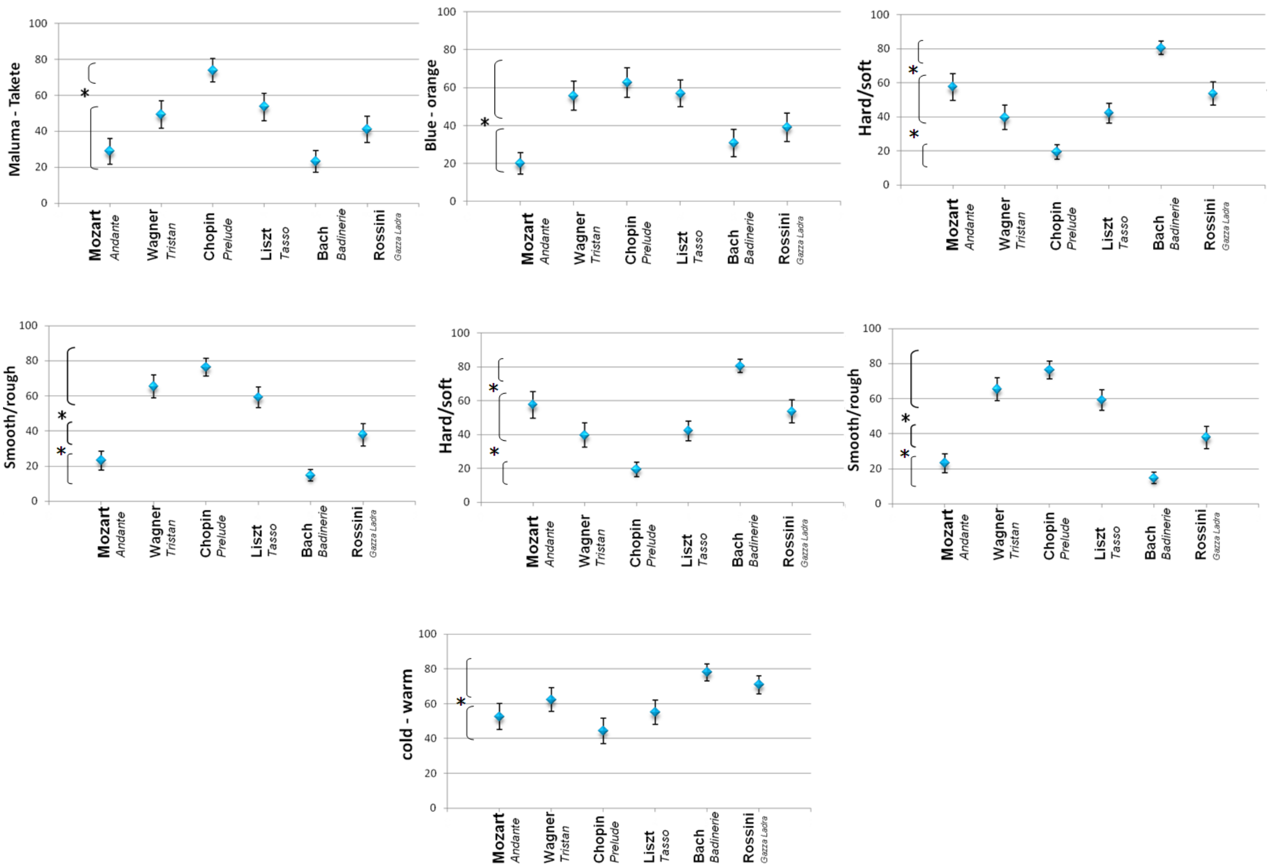

Figure 4: The average scores obtained by the six musical excerpts of Experiment 2 on the seven sensory scales. Bars indicate the standard error.

The same happens for 3 (Chopin), considered the hardest, and significantly differentiated from every other stimulus. As regards the scales smooth/rough, bitter/sweet and heavy/light, significant differences can be seen between excerpts 1, 5, 6 and 2, 3, 4 respectively. This result is particularly relevant for the fact that the group formed by tracks 1, 5, 6 is characterized by smoothness, sweetness and lightness as opposed to the roughness, bitterness and heaviness of the other triad. Inside the scale smooth/rough, even excerpt 3 is differentiated from 4, thus emphasizing the roughness of Chopin's Prelude as opposed to Liszt's symphonic poem. As regards the scale cold/warm, the key excerpt is n. 5, which is felt as the warmest and which is significantly different from stimuli 1, 3 and 4. In this scale we don't find extreme values, since it is characterized by great inter-participants variability, determining similar average values. Strangely enough, Wagner is perceived as warmer than Mozart and this is probably due to the fact that this excerpt is perceived as more violent and the heat was intended as a quality associated with burning.

Table 2: Significant p values with FDR correction of the differences between pairs of excerpts of Experiment 2. Blank cell means $p > .05$

	Ma/Ta	Bl/Or	Ha/So	Sm/Ro	Bi/Sw	He/Li	Co/Wa
1-2		<.001		<.001	.002	.001	
1-3	.001	<.001	.001	<.001	.015	.001	
1-4		<.001		<.001	.029	.002	
1-5			.016		.001	.004	.013
1-6		.050					
2-3	.047		.020				
2-4							
2-5		.050	<.001	<.001	<.001	<.001	
2-6				.008	<.001	<.001	
3-4			.020	.042			
3-5	<.001	.050	<.001	<.001	<.001	<.001	.013
3-6	.012		.001	<.001	<.001	.002	.024
4-5	.011	.050	<.001	<.001	<.001	<.001	.039
4-6				.042	<.001	.006	
5-6			.007	.008	.002	.006	

6 Discussion

As can be seen in Figure 3 and 4, participants' ratings on sensory scales tended to configure according to a similar profile with great consistency. The quality "maluma" always couples with "blue", while the quality "takete" always couples with "orange". The only exception was excerpt 2 in Experiment 2, R. Wagner, Tristan, Act 3, in which the quality orange and maluma were associated, even if with very low values. Probably this exception is due to the fact that this excerpt combines a slow tempo with a strong dramatization due to many sudden crescendos. The association of low arousal and negative valence may have inspired some particular correlation between the colours and the shapes. In both experiments, Mozart (flute concerto and piano concerto) is evaluated as the bluest and most maluma composer, together with Bach (Badinerie) and Brahms (violin concerto).

As regards the sensory scales, we see how maluma/takete, smooth/rough, sweet/bitter and light/heavy could differentiate between musical examples. More problematic were the scales blue/orange and soft/hard; these two scales didn't provide significant values, apart from the blue quality of Mozart's piano concerto and Bach's Badinerie and the soft quality of Brahms' violin concerto and Mozart's flute concerto. This result can be compared with research based on the association between music and colours. Researchers at the University of Berkeley found that people tended to pair faster-paced music in a major key with lighter, more vivid, yellow colours, whereas slower-paced music in a minor key was more likely to be teamed up with darker, greyer, bluer colours (Palmer et al., 2013). Also in our study, music in the minor mode was in general associated with blue colours.

In order to observe the interaction of the semantic scales with the sensory ones, Table 3 and 4 show the qualities of the six excerpts of Experiment 1 and 2, based on the subjects' evaluation. In particular, only rates significantly different from 50 (the middle point of the evaluation scale) are reported. It is interesting to notice how Bizet (3 Exp 1), Brahms' horn trio (6 Exp 1), Chopin (3 Exp 2) and Liszt (4 Exp 2), described verbally with the same characteristics, (active, interesting, fast, deep, tense, masculine, complex, shaken, open air and violent), receive significantly different sensorial results. This makes us suppose that sensory scales can convey some specific sensations that cannot be described verbally. Both Brahms' horn trio and Chopin are in triple meter with significant changes from ternary to binary subdivision, they share a similar articulation (many notes played marcato) performed by the violin and by the right hand of the pianist and a common accompaniment based on repeated piano octaves. Participants

Table 3: The qualities of the six excerpts of Experiment 1, based on the subjects' evaluation. Blank cells mean that no significant trend has been found.

1	2	3	4	5	6
maluma	takete	takete	maluma	takete	takete
soft			soft		
smooth	smooth		smooth	smooth	rough
sweet			sweet		bitter
light			light		heavy
warm			warm		cold
	Active	Active	Passive	Active	Active
	Interesting	Interesting	Interesting	Interesting	Interesting
Slow	Fast	Fast	Slow	Fast	Fast
	Superficial	Deep	Deep	Superficial	Deep
Relaxed		Tense	Relaxed		Tense
Feminine		Masculine	Feminine		Masculine
Clear	Clear		Clear	Clear	
Desirable	Desirable	Desirable	Desirable	Desirable	
	Brilliant	Brilliant		Brilliant	
Simple		Complex	Simple	Simple	Complex
Calm	Shaken	Shaken	Calm	Shaken	Shaken
Intimate	Open air	Open air	Intimate	Open air	
Gentle	Gentle		Gentle	Gentle	Violent

were however able to recognize a slight sensory difference between the two pieces, represented by Chopin's higher hardness, due to the presence of many accents, and by Brahms' higher coldness, due to the obsessiveness of the rhythmic configuration. Another interesting result deriving from sensory scales is represented by the apparent unusual association of the quality takete with the quality smooth applied to Vivaldi (2 Exp 1) and Boccherini (5 Exp 1). Also in this case participants' evaluation seems to recall timbral elements; the staccato and pizzicato generate an idea of sharpness delimiting only the contours of an ideal figure perceived as covered by a smooth surface. Comparing the two Mozart excerpts (4 Exp 1 and 1 Exp 2), we see that they have 12 features in common (maluma, smooth, interesting, slow, deep, relaxed, clear, desirable, simple, calm, intimate, gentle). The flute concerto differs from the piano concerto in softness, smoothness, sweetness, lightness and warmness, while, from the verbal point of view, we can recognize their diversity only from the higher darkness of the piano concerto. In this case, the qualities underlined by sensory scales offer us some hints about some ineffable aspect of the music related to affect, allowing insights into the depressive and sombre atmosphere of the second excerpt. Also Brahms' violin concerto (1 Exp 1) and Bach's Badinerie (5 Exp 2) have 12 features in common, but in this case, sensory scales report a similarity which is not matched by verbal scales. Verbal scales are crucial in discriminating the swiftness and brilliantness of Bach, but the sensory scales provide useful information about timbral aspects, since both stimuli are played by two wind instruments (oboe and flute) with a particularly warm, soft and rich sound. Further research is needed to confirm our hypothesis on the kind of information provided by sensory scales. In particular, it is interesting to verify which kind of metric relations (if any) can be found between the sensory scales (e.g. see Zaidi et al. (2013)). This step could further the definition of a low-dimensional sensory space, to be used in music information retrieval applications.

Table 4: The qualities of the six excerpts of Experiment 2, based on the subjects' evaluation. Blank cells mean that no significant trend has been found.

1	2	3	4	5	6
maluma		takete		maluma	
blue				blue	
		hard		soft	
smooth	rough	rough		smooth	
	bitter	bitter	bitter	sweet	sweet
	heavy	heavy	heavy	light	
				warm	warm
	Active	Active	Active	Active	Active
Interesting	Interesting	Interesting	Interesting	Interesting	Interesting
Slow	Slow	Fast	Fast	Fast	Fast
Deep	Deep	Deep	Deep	Deep	
Relaxed	Tense	Tense	Tense	Relaxed	Tense
	Masculine	Masculine	Masculine	Feminine	
Clear				Clear	Clear
Desirable				Desirable	Desirable
Dark	Dark			Brilliant	Brilliant
Simple	Complex	Complex	Complex	Simple	
Calm	Shaken	Shaken	Shaken		Shaken
Intimate			Open air		Open air
Gentle		Violent	Violent	Gentle	

7 Conclusions

Two experiments were carried out in order to test the possibility of describing music qualities through non verbal sensory scales. The overall findings indicate that subjects' rates on sensory scales are consistent and the results support the hypothesis that sensory scales can provide a useful tool in order to investigate crossmodal relationships. An interesting example is represented by the coupling of the two apparently opposite qualities takete and smooth as characterising the excerpts by Vivaldi and Boccherini. These two tracks share the same verbal labels, but none of them can catch this apparent paradox which is an intrinsic feature of music multifaceted nature. Sensory scales seem to be able to depict music timbral aspects and imaginative shades which escape a linguistic definition.

Results confirm that the tool created for our experiments provides a novel way of allowing qualities of music to be differentiated. The consistency of results suggests the application of sensory scales to other musical cultures, styles and genres overcoming the boundaries of Western classical music. Since features (acoustic, structural, style-related, or cultural) of the music used in the experiments are not controlled or systematically accounted for, further experiments are needed in order to relate sensory scales to these features.

From the application point of view, such research can foster the development of innovative interfaces to browse audio digital collections. These new devices will allow users to interrelate in a spontaneous and even expressive way with interactive multimedia systems, relying on a set of advanced musical and gestural content processing tools adapted to the profiles of individual users, adopting descriptions of perceived qualities, or making expressive movements.

Another interesting application regards the exploration of the timbre space of a synthesis algorithm, allowing the transition between one timbre to the other in an intuitive way. By exploiting the potentialities of metaphoric associations, musicians will be able to navigate timbre spaces generated by synthesis algorithms with easiness in exploring unknown sounds.

This study paves the way for new experiments investigating if evaluations based on non verbal sensory scales provide different or complementary results from evaluations based on the verbalization of the same sensory scales. Results could identify possible intrinsic aspects of music, underlining qualities that are general, universal, valid *prima facie* for any listener, but, at the same time, the expression of subjective and personal characterizations.

Advances in music research need to be based on the collaboration of multiple research fields such as musicology, psychology and engineering, in synergy with artistic explorations. Such research should deepen our knowledge on the relationship between music and other sensorial experiences, overcoming the limits imposed by verbal scales and helping to develop a holistic consciousness of musical expressive content.

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A Appendix: description of the musical excerpts

Experiment 1.

1 - J. Brahms - Violin Concert in D major, op. 77, 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. The doubling of lines serves to reinforce the fullness of sound of the whole.
2 - A. Vivaldi - Trio Sonata in C major, RV82, Allegro. Vigorous and cheerful passage, characterized by a thematic development entrusted to the combination of lute and violin. The violin plays rapid trills, thus complementing the lute's quick, athletic ornaments with its own sharp notes. The ascending tone is emphasized by the intensive use of progressions enriched by the continuous dialogue between lute and violin.
3 - G. Bizet - Symphony no. 1 in C major, Allegro vivo. The work starts with an opening tutti full of strength and force, like a brisk announcement. This bold first idea is answered by a timid pp reply by the winds which are soon harassed again by the tutti repeating the same announcement this time leading to G major.
4 - W. A. Mozart - Flute Concerto G Major, II. Andante non Troppo. Gentle and relaxed theme developed by the flute through an expanse figuration of demisemiquavers. The orchestra accompanies this quiet moment with soft pizzicato and tender eight notes, while the violin answers the flute with responding demisemiquavers figurations.
5 - L. Boccherini - String Quintet in E major, op. 11, no. 5, Minuetto. This popular piece is full of grace and elegance. The dance rhythm is underlined by the upbeat quarter line in the first violin embellished by a characteristic grace note.
6 - J. Brahms - Trio, piano, violin, 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.

Experiment 2.

1 - W. A. Mozart, Piano concerto Adagio, K 488. Theme in a minor key, played at a very slow tempo. Melancholic trochaic rhythm characterized by a large intervallic distance between sounds grouped by the left hand, and the melody in the high register of the right hand, creating a void in the middle of the range which reinforces the desolate aspect of the theme.
2 - 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.

3 - F. Chopin, Prelude 22. Motif in the low register of the piano repeated obsessively and characterized 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.
4 - F. Liszt, Tasso Lamento and Trionfo (from letter A ï£¡ allegro strepitoso). Powerful orchestral line develops tense minor harmonies on a choppy rhythm and at a rapid tempo, supported by the entry of the percussion.
5 - J. S. Bach, Badinerie from Orchestral Suite n. 2 BWV 1067. Exposition of the main theme by the flute in the typical dance rhythm characterized by a joyous and light feeling. The orchestral accompaniment is very simple and elegant.
6 - G. Rossini, La Gazza Ladra (The Thieving Magpie) - Allegro con brio. Particularly fast and tense orchestral passage characterized by frequent accents and chromatic contrasts. Triplets figurations in the violins and violas are punctuated by the other strings playing a very pressing and obstinate rhythm.