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In this paper, we investigate how the notion of violin quality is conveyed in spontaneous verbalizations by experienced violinists during preference judgments. The aims of the study were to better understand how musicians conceptualize violin quality, what aspects of the sound and the playing experience are essential, and what associations are formed between perceptual evaluation and physical description. Upon comparing violins of varying make and age, players were interviewed about their preferences using open-ended questions. Concepts of violin quality were identified and categorized based on the syntactic and linguistic analysis of musicians' responses. While perceived variations in how a violin sounds and feels, and consequently conceptualization structures, rely on the variations in style and expertise of different violinists, the broader semantic categories emerging from sensory descriptions remain common across performers with diverse musical profiles, reflecting a shared perception of physical parameter patterns that allowed us to develop a musician-driven framework for understanding how the dynamic behavior of a violin might relate to its perceived quality. Implications for timbre perception and the crossmodal audio-tactile sensation of sound in music performance are discussed.

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I. INTRODUCTION

When evaluating violins, performers spontaneously describe perceived quality characteristics calling upon a diverse vocabulary, for example, rich sound, responsive instrument, even sound across strings, and clear notes. This lexicon, shared not only by violinists but also by other instrumentalists, is traditionally communicated from teacher to student and between musicians and instrument makers. In the present study, we adopted a psycholinguistic approach to investigate how violin quality is conceptualized in the mind of the violinist as reflected in free verbalizations collected from experienced musicians during playing-based preference ranking and attribute rating tasks, using a method that relies on theoretical assumptions about cognitive-semantic categories and how they relate to natural language.

In the context of relating the dynamic behavior of a violin to its perceived quality, a number of studies have tried to match such verbal attributes with features of structural dynamics measurements or recorded audio signals. Analyzing radiation measurements, Meinel (1957) and Dünnwald (1991) each suggested similar divisions of the violin's frequency response into four quality-critical regions: high-amplitude resonances at low frequencies below about 800 Hz give full sound that carries well; the more weak the response in the vicinity of 1.5 kHz, the less nasal the sound is; a strong peak around 2–3 kHz (today known as the bridge hill) is associated with brilliance and effective radiation; and low-amplitude resonances at high frequencies above about 3 kHz allow a soft and clear sound.

Based on observations from bridge mobility measurements on over 100 violins with "a wide variety of tone and playing qualities, as described by their owners-players," Hutchins (1989) argued that violins with a difference of less than 40 Hz between the $B1^+$ and A1 resonances were easy to play with little projection; violins in the 55–70 Hz range were more powerful in terms of projection; and above 100 Hz instruments were harsh and hard to play. According to Schleske (2002), violins with $B1^+ < 510$ Hz versus > 550 Hz are soft versus harsh, less versus more resistant, and characterized by dark versus bright sound.[1]

In a study on violin sound projection by Loos (1995) strong lower partials in a note appeared to enhance its perceived nearness. In another study by Štěpánek and Otčenášek (1999) it was observed that violin notes described as sharp and narrow were associated with higher and lower spectral centroid values, respectively, while a perception of rustle was attributed to temporal changes of the spectral energy around the A0, $B1^-$ and $B1^+$ modes. Łukasik (2005) proposed that the first cepstral coefficient is associated with the bipolar linguistic pair strained:light; the spectral centroid with bright:dark; the tristimulus 1 and 3 with deep/full:flat/empty; and a coefficient of steady-state envelope fluctuation with smooth:coarse, but listening tests did not confirm the scheme. In one of our previous studies, we found that low spectral centroid and high tristimulus 1 and 2 values are likely associated with a rich sound (Saitis *et al.*, 2015). Hermes *et al.* (2016) reported evidence of a strong positive correlation between the harmonic centroid of a violin note and its perceived clarity.

Fritz *et al.* (2012a) had violinists arrange 61 sound-descriptive adjectives on a two-dimensional map, so that words with similar meanings lay close together and those with different meanings lay far apart. Multidimensional scaling revealed three perceptual dimensions (acoustical interpretations proposed by the authors): warm/rich/mellow:metallic/cold/harsh (spectral balance, undesirable qualities associated with excessive high-frequency content or too little low-frequency content); bright/responsive/lively:muted/dull/dead ("amount of sound" produced by the instrument, particularly in the middle and upper ranges); and even/soft/light:brash/rough/raspy (noisy character, width of distribution of spectral energy). A listening experiment using virtual violin sounds with modified amplitudes of vibration modes in five one-octave wide bands showed that, in contrast with Meinel and Dünnwald's observations, increased brightness and clarity were associated with moderately increased modal amplitudes in the 1520–6080 Hz region, whereas increased harshness was associated with a strongly increased modal level in the 1520–3040 Hz band.

A potential issue with interpreting the outcomes of these studies is that the investigated verbal descriptors are part of a lexicon that is often taken for granted in the design of perceptual evaluation studies, as opposed to identifying relevant semantic descriptors emerging from a systematic linguistic analysis of the verbalizations spontaneously used by musicians to describe instrument quality. Fritz *et al.* (2010) were the first to carry out such an analysis of violin quality perception, but only collected data from three musicians.

Relationships between measurable physical properties of sound-producing objects, such as musical instruments, and their perceived characteristics rely on cognitive representations of both auditory and haptic phenomena, which, however, cannot be accessed in a direct, quantitative way. The psycholinguistic analysis of how people spontaneously describe their experience of acoustic and vibrotactile stimulations can be considered as one way to study these representations empirically (Dubois, 2000). Instead of starting from physical properties of sounds or their sources to describe cognitive representations, semantic categories are identified first through the analysis of linguistic descriptions. Language can be seen as mediating between collective knowledge and individual representations conveyed in discourse. From what is being said (content analysis) and how it is being said (psycholinguistic analysis), relevant inferences about how people process and conceptualize sensory experiences can be derived (semantic level) and further correlated with physical parameters (perceptual level).

Psycholinguistic studies of urban soundscape quality have shown that the meanings attributed to sounds in everyday sensory experiences act as a determinant for evaluations, in addition to or independently of physical parameters of the acoustic signal (Guastavino, 2006; Dubois *et al.*, 2006). Semantic-linguistic analyses of musical instrument quality descriptions have revealed that structural properties or audio features traditionally used to describe certain perceptual attributes cannot always explain the cognitive categories emerging in the musicians' verbalizations, which in turn can provide novel insights into defining meaningful and unambiguous quality descriptors to distinguish one instrument (or one performer) from another—for example, semantic synonyms and opposites, or relations between gestural control and desired sound (Faure, 2000; Rioux and Västfjäll, 2001; Traube, 2004; Bellemare and Traube, 2005; Bensa *et al.*, 2005; Cheminée, 2009; Bernays and Traube, 2013; Lavoie, 2013; Paté *et al.*, 2015).

When Fritz *et al.* (2010) examined the differences between preference judgments made by three violin players in active playing vs. passive listening situations in conjunction with psycholinguistic analyses of free-format verbal descriptions of the musicians' experience, they found that the overall evaluation of a violin as reflected in the verbal responses of the musicians varied between playing and listening conditions, the former invoking descriptions influenced not only from the produced sound but also by the interaction between the player and the instrument.

Accordingly, we carried out two violin playing perceptual tests based on a carefully controlled yet musically meaningful protocol. In the first experiment, skilled violinists ranked a set of different violins from least to most preferred. In experiment 2, another group of players rated a different set of violins according to specific attributes as well as preference. In both tasks, musicians verbally described their choices through open-ended questions. We previously showed that violinists are self-consistent in their (nonverbal) preference judgments and tend to agree on what qualities they look for in a violin, but a significant lack of agreement between individuals was observed, likely because different violinists assess the same attributes in different ways (Saitis *et al.*, 2011, 2012). A third experiment (Saitis *et al.*, 2015) and studies by Fritz *et al.* (2012b, 2014) and Wollman *et al.* (2014a,b) reached similar conclusions.

In this study, we investigated the perceptual and cognitive processes involved when violinists evaluate violins by focusing on the linguistic expressions they use to describe quality characteristics. Expanding on the work of Fritz *et al.* (2010), the free verbalizations collected in the two playing tests were analyzed on the basis of semantic proximities in order to identify emerging concepts that could be coded under broader categories acting as psychologically relevant descriptors of violin quality. Semantic proximities were inferred from syntactic context and linguistic markers. The coding process was based on the inductive principle of Grounded Theory, where a system of ideas is constructed not starting from a hypothesis (or a set of hypotheses) but from the data itself (Strauss and Corbin, 1998). An acoustical interpretation of the semantic categories-descriptors is proposed as a first step in translating the semantics of musicians' expressions into hypotheses for explaining links between perceptual judgments and physical description.

II. METHOD

A. Musicians, violins and controls

Twenty violinists participated in experiment 1 (8 females, 12 males; average age = 34 yrs, SD = 13 yrs, range = 20–65 yrs). They had at least 15 years of violin experience (average years of violin training = 26 yrs, SD = 12 yrs, range = 15–60 yrs). Experiment 2 involved 13 violinists (9 females, 4 males; average age = 28 yrs, SD = 9 yrs, range = 21–53 yrs) that had at least 12 years of violin experience (average years of violin training = 22 yrs, SD = 9 yrs, range = 12–46 yrs). In both experiments, musicians were remunerated for their participation. Of the 13 players in the experiment 2, 3 had previously participated in experiment 1. Musical profile information for each violinist is reported in Table I.

In both experiments, the tested violins were chosen from several local luthier workshops in order to form, as much as possible, a set of instruments with a wide range of characteristics (Table II). The respective luthiers provided the price estimates and tuned the instruments for optimal playing condition based on their own criteria. The fact that some violins may have been less optimally tuned or had strings of varying quality was not a concern, as that should not influence the consistency of the evaluations.

Low light conditions and dark sunglasses were used to help hide the identity of the instruments as much as possible and thus circumvent the potential impact of visual information on judgment while ensuring a certain level of comfort for the musicians, as well as safety for the violins. To avoid the potential problems of using a common bow across all participants (e.g., musicians being uncomfortable with a bow they are not familiar with, bow quality), each violinist used their own bow. Sessions took place in acoustically dry rooms to help minimize the effects of room reflections on the direct sound from the violins.

B. Questionnaire and procedure

Taking into account the lingual diversity of Québec, a bilingual questionnaire in English and French was compiled for each study, and participants were invited to respond in the language they felt most comfortable with. To avoid confining the responses into pre-existing categories, very general open-ended questions were formed, wherein no restriction was imposed on the format of the response. Five participants from experiment 1 and three participants from experiment 2 chose to reply in French and it was decided not to translate their responses but include them in the analysis directly.[2]

In experiment 1, participants preference-ranked 8 violins in 5 identical trials. Each time they had up to 15 min to play and rank the instruments. Upon completing the first trial, participants justified their choices by providing written responses to the following set of task-specific questions (French version is given in parentheses):

A1. How and based on which criteria did you make your ranking? (Avec quels critères avez-vous effectué votre classement et de quelle façon les avez-vous utilisés?)

A2. Considering the violin that you ranked as “most preferred,” can you say why? (A propos du violon que vous avez classé comme votre préféré: pourriez-vous nous dire pourquoi?)

A3. Considering the violin that you ranked as “least preferred,” can you say why? (A propos du violon que vous avez classé en dernier: pourriez-vous nous dire pourquoi?)

At the end of each subsequent trial, musicians could modify their initial response to any of the above questions if they so wished. Upon completing the last trial, participants answered a more general question:

B. More generally, what is a very good violin for you? (En général, comment définissez-vous personnellement un très bon violon?)

Violinists returned for a second, identical session 3–7 days later, wherein they provided written responses to the same questions. All participants answered questions A1–A3 in up to 4 trials as well as question B in each session.

In experiment 2, musicians rated a different set of 10 violins according to ease of playing, response, richness, dynamic range, balance across strings and overall preference (one violin on all scales at a time) in three blocks of repetitions. They had up to 5 min to play and rate each instrument. The attributes were chosen based on a previous, more rudimentary analysis of the verbal responses to question A1 in experiment 1 (Saitis *et al.*, 2012, Sec. II B 4). At the end of the session, all participants provided written responses to question B.

In both experiments, violinists were instructed to follow their own evaluation strategy with respect to what and how to play. Prior to the actual tasks, they were encouraged to play and familiarize with the different violins for up to 20 min.

C. Analysis

In their original conception of Grounded Theory, both Glaser and Strauss acknowledged that "the researcher will not enter the field free from ideas" (Heath and Cowley, 2004), but their views on the role of prior ideas later diverged. Strauss and Corbin (1998) argued that specific understandings from past experience and literature can be used to inform the development of categories, whereas for Glaser (1978) this is to be avoided in order to maintain sensitivity to the data. In the present study, prior knowledge of the researchers as well as previous findings in the literature and informal discussions with musicians, luthiers and colleagues were considered as per the view of Strauss and Corbin.

Grounded Theory relies on several data coding steps, not strictly sequential, which form the so-called constant comparison method. According to Strauss and Corbin (1998) these are: open coding, wherein key concepts are identified; axial coding, wherein concepts are linked based on semantic proximities, yielding semantic categories and inter-categorical associations; theoretical sampling and selective coding, wherein new data are selectively sampled with the emerging conceptual framework in mind and integrated to potentially improve it; and theoretical saturation, wherein coding concludes when categories do not develop further (i.e., no new concepts emerge) despite new data.

Appropriately, our analysis started from the verbalizations collected in experiment 1. First, group of words indicating a concept of violin quality, henceforth called verbal units, were extracted from musicians' responses to questions A1–A3 and classified in semantic categories (open coding). Inter-categorical associations were then established (axial coding), at which point a tentative core for our conceptual framework had been formed. We next scanned the verbal responses to question B (theoretical sampling). New concepts were identified and the core was updated to fit with the new data (selective coding). The analysis was then extended to the verbal responses collected in experiment 2 (question B only) on the basis of the updated core (theoretical sampling), wherein no further concepts emerged. Consequently coding was stopped as theoretical saturation had been reached.

Each verbal unit corresponded to a semantically distinct violin quality characteristic. Semantic proximities were assessed through syntactic context and linguistic markers such as the use of apposition, opposition, reformulation, explanation, comparison, or negation. For example, the phrase *"a rich, velvety tone"* contained two verbal units, namely "rich" and "velvety," whereas the phrase *"can cut across a hall but not to such an extreme that it sounds shaved on the top"* constituted a single unit which, however, comprised two manifestations of the same quality characteristic with opposite meanings, namely "can cut across the hall" (positive connotation or desirable quality) and "sounds shaved on the top" (negative connotation or undesirable quality). In total, 766 verbal units were extracted from the responses collected in experiment 1 (20 musicians, 4 questions, 38 units per respondent on average) and 62 units (13 musicans, 1 question, 5 units per respondent on average) in experiment 2, and were classified in eight distinct semantic categories.

We provide some examples from the collected verbalizations to better illustrate the analysis method. One participant said: *"Essentially I was looking for ... "flexibility" (i.e., the ease with which I could produce a variety of different sounds and timbres) and a kind of resonance that seems to last well beyond each note. Beyond that, balance across all the strings is also important (i.e., the timbre and power remain even across all the strings)."* Here it was inferred that: "flexibility" and "ease" are semantically very close; "resonance" is associated with the sustain level of a played note; "balance" and "even" are also related to one another.

Another violinist commented: *"A weaker violin will tend to sound as if there is something inhibiting the sound - the sound will sound strangled or will break or scratch under bow weight."* In this example, it was first inferred that "weaker" and "inhibiting" are: related to one another; related to "strangled" and thus associated with sound intensity; related to "break" and "scratch" and thus associated with sound production and the interaction between musician and instrument.

It was further inferred that "break" and "scratch" are semantically very close.

Illustrating the polysemy often found in lexical semantics, a final example shows a relationship between "clarity of sound" and articulation (i.e., successive notes played quickly do not "meld" together). From another musician's response: *"I also listened for a muddy sound. Some of the less well made violins have this sort of blurry sound, where even if you play notes quickly they meld together, while the instruments with the brighter sound seem to sound clearer."* Here it was inferred that "muddy" and "blurry" are semantically close to one another and opposites of "clearer" and "brighter," respectively, in the context of articulation. It was also inferred that "clearer" and "brighter" are related to one another.

III. RESULTS

A. Objects of reference and directed attributes

Semantic categories of violin quality evaluation emerged from the syntactic and linguistic analysis of musicians' verbal responses by progressively examining the cognitive objects of reference—What is being evaluated?—the linguistic resources directed to these objects—How is it evaluated?—and the semantic dimensions underlying the used lexicon—What does it mean? There were primarily two distinct cognitive objects of evaluation for the violinist in the present corpus, namely the violin-player interaction, as the physical direct interaction with the instrument, and the produced sound, as the perceived result of this interaction.

The emerging semantic dimensions of the lexicon used to describe perceptual attributes of the sound can be summarized as texture (e.g., round, complex, muddy), luminance (e.g., clear, bright, blurry), mass (e.g., full, deep, hollow), action-presence (e.g., powerful, present, strangled), balance [across strings] (e.g., even, balanced, uneven), and interest (e.g., beautiful, interesting, irritating). Referring to material object properties, the texture, luminance and mass dimensions indicate an evaluation of structural (i.e., related to timbre and intensity) attributes, for example relative amount of high-frequency content or total spectral energy. The more abstract dimension of action-presence suggests an assessment of "how much sound" comes out of the violin based on estimated spatial attributes (e.g., projection), but also on the "amount of felt vibrations" from the body-bow system (i.e., vibrotactile cues). Interest assumes a cognitive evaluation of the subjective-affective value of the played sound, an axiological evaluation. The balance dimension indicates a comparative evaluation of structural attributes between different notes and strings. The dimensions of interest and balance emerged also in descriptions referring to the violin-player interaction. Central to the latter were the concepts of ease and speed of response (e.g., responsive, quick, rigid), indicating an evaluation of proprioceptive (i.e., reactive force) attributes.

As an example, one participant commented: *"An instrument that is good needs to feel comfortable, sound interesting and round, with enough complexity in the sound (i.e., overtones) that I can get a variety of sounds with ease."* Here "comfortable" and "ease" refer to proprioceptive attributes of the physical interaction of the performer with the instrument, whereas "interesting" describes an affective value attributed to the played sound and "round" and "complexity" refer to its spectral content (structural attributes). Two of the preference criteria reported by another violinist were: *" . . . projection of that sound, vibrancy of the sound, ..."* In this example the played sound is evaluated through the attribution of spatial ("projection") and vibrotactile ("vibrancy") characteristics. In describing their idea of a good violin, one musician said *"It doesn't need to be perfect across the board, but it needs to respond interestingly to different approaches."* and another remarked that *"It is . . . consistent in playability and tone."* Here "perfect" and "interestingly" denote subjective-affective values attributed to the violin-player interaction, while "consistent" signifies that proprioceptive and structural attributes are assessed comparatively across notes and strings.

B. Semantic categories

The resulting categorization is summarized in Table III. The label for each category, hereafter reported in SMALL CAPITAL letters, was chosen either among the words of the respective category, often being the one most frequently used by the musicians, or based on the main underlying semantic dimension (see previous section). Unique phrases from verbal units are reported together with the number of occurrences across all verbal units coded in the respective category (i.e., a verbal unit may contain more than one unique phrase). Morphological variants were transformed from a descriptive noun, adverb, or verb into adjectival form and grouped together (e.g., ease of playing → easy to play, richness → rich). When unambiguous, French expressions were considered together with their direct English translations (e.g., *facile a jouer* → easy to play, *richesse* → rich). Cognitively these unique phrases represent *microconcepts*—the most basic concepts (i.e., minimal elements of knowledge) activated by a stimulus object (here the violin sound or body-bow response and vibrations) which are not meaningful on their own but instead yield meaning when assembled into broader semantic patterns-categories (Bassili and Brown, 2005; Conrey and Smith, 2007).

Manifestations of the same quality characteristic with opposite meanings were coded in the same category. For each microconcept, its positive (+) or negative (−) orientation was inferred from the syntactic and semantic context wherein it occurred (see Sec. II C). The smaller number of "negative" versus "positive" expressions might have been a result of the particular way questions were formatted. When asked to explain their preference criteria (question A1), justify their most preferred choice (question A2), or describe their idea of a very good violin (question B), participants naturally focused on discussing desirable quality features. Problems and unfavorable qualities were largely commented only when musicians were asked to explain why they chose violin X as their least preferred (question A3).

Under RICHNESS are verbal expressions referring to the amount of spectral content as in the perceived number of partial frequencies present in a violin note. Desirable attributes are associated with an abundance of partials, where it is possible for the performer to produce "different sounds" based on musical (repertoire) and affective (emotion) intentions. Also referring to spectral content, expressions grouped under TEXTURE direct to the distribution of partials between the bass and treble registers in a played note. Undesirable qualities are associated with disproportionately more treble or not enough bass frequencies. On the whole, RICHNESS and TEXTURE encompass steady-state timbre characteristics of the sound.

RESONANCE groups together verbal descriptions that refer to the intensity of the radiated sound "under the ear" as perceived crossmodally through two physical channels: total energy in the acoustic signal during sustain and release, and felt vibrations (i.e., motions and deformations of skin mechanoreceptors) from the violin body and bowed string. Spectral energy further evokes a different category of verbal expressions, which describe the intensity of the radiated sound in terms of spatial attributes, i.e., transmission from the instrument to the performance space. These are summarized by the meta-criterion PROJECTION.

RESPONSE comprises descriptions of how quickly the violin responds to different configurations of bowing parameters (force, velocity, position on the string, tilting with respect to the string) in terms of transients, dynamics, and fast passages (articulation), and thus how easy and flexible it is for the violinist to interact with the instrument and control the played sound. Grouped here are also descriptions referring to the size and weight of the violin, including the string height or action, as design factors contributing to the instrument's response. Physically, expressions such as "easy to play" and "responsive" indicate that the player feels the reactive force (proprioceptive feedback) from the violin body in the right hand (via the bow) and assesses its amount and how fast it emerges in relation to how "good" the resulting sound is.

CLARITY captures verbalizations that refer to (the lack of) audible artifacts in the played note, such as wolf tones (i.e., oscillating beat when note frequency too close to the resonance frequency of the violin body), "buzzing" coming from loose or faulty fittings in the different parts of the instrument, slow and deficient buildup of partials in bowed string attacks and transients, the "melding" together of successive notes when played quickly (here articulation is evaluated based on audio information rather than proprioception), or different notes masking each other due to overlapping content. A sound is described as "clear" when perceived as having more distinct and well-defined spectral components. CLARITY and RESPONSE incorporate aspects of the instrument's playability as evaluated based on auditory and haptic information, respectively.

BALANCE sums up expressions referring to the lack of striking differences across notes and strings in both the physical response of the violin (e.g., one or several strings being harder to play or slower to respond to varying gestures than the others) and the timbre and intensity of the produced sound (e.g., notes played on one string having too much or too little frequency content or spectral energy compared to those played on the other strings).

INTEREST groups together verbalizations describing the subjective-affective state of the musician in response to their physical interaction with the violin and the acoustical characteristics of its sound, as well as abstract, context-free references to sound quality such as "timbre" of the strings, "color" of the sound, or "tone quality," where it was not possible to identify associated concepts. To illustrate this difference, one violinist said *"Again, the easily-producible singing quality of this instrument made it stand out from the others."* (attributive reference), while another responded *"I liked the tone quality of my first choice."* (abstract reference). While semantic categories identified until now describe sensory attributes, INTEREST refers to affective or hedonic qualities that do not reflect the perception of certain physical parameters.

A microconcept can be recruited into many different evaluations depending on context and thus coded in more than one semantic categories or as both positive and negative within the same category. In the present corpus, the word "even" was used to denote either a balanced spectrum with no excessive high-frequency content or a consistent sound and playing sensation across different notes and strings. "Bright" had three distinct meanings: lively (lots of energy), clear (well-defined spectral components), and warm (balanced spectrum). In the same semantic category as warm, bright was also used negatively to denote excessive high-frequency content. The adjective "weak" described either structural (not enough energy in the spectrum) or spatial (inadequate projection) attributes of the sound. The antonym pair "small-big" referred either to the physical dimensions of a violin (with small being preferable to big) or to how much sound it produces (here small was valued negatively). The phrase "muted overtones" indicated a short number of activated partials, while "muted sound" meant lacking in total spectral energy. Finally, the French noun "*focus*" meant either clarity (well-defined partials) or balance across the strings (referred to both the sound and the playing behavior).

Table I reports the musical profile of each participant along with information on whether they used verbal expressions within a given category. No obvious relationship between having a certain style and/or level of experience and attending to particular attributes was observed. Consequently, Table IV summarizes the across musicians distribution of semantic categories within each and over all responses to the different questions. In experiment 1, distributions were comparable between trials in each session as well between sessions, so occurrences were collapsed respectively. The proportion of verbal units referring to the sound versus those describing the violin-player interaction in each of the two experiments, as well the distribution of attribute types directed to each of the two cognitive objects of evaluation in either corpus is shown in Table V. In experiment 1, occurrences were further summarized across questions due to similar trends.

IV. DISCUSSION

A. The perspective of the violinist

The present analysis offers novel insights into the perception of violin quality by performers. The psycholinguistic analysis of their spontaneous verbalizations produced in playing-based violin preference judgments showed that they conceptualize violin quality on the basis of semantic features and psychological effects that integrate perceptual attributes (i.e., perceptual correlates of physical characteristics) of both the sound produced and the somatosensation experienced when playing the instrument.

As Traube (2004) noticed, the perspective of the player is at the same time that of a musician and a listener. To the bowing of the string, the violin responds by providing information communicated to the player-musician via vibrotactile and proprioceptive channels (RESONANCE, RESPONSE, BALANCE) and by producing a sound processed by the player-listener though the au-

FIG. 1. Placed approximately here.

ditory modality (RICHNESS, TEXTURE, CLARITY, RESONANCE, PROJECTION, BALANCE). The combined audio-haptic sensory information is also perceived in a subjective-affective dimension related to musical and emotional situations relevant to the player-musician-listener (INTEREST). The perception of quality is thus elaborated not only from sensations linked to physical input, but also from non-sensory contextual factors associated with previous experience such as memory and training, and interpretation processes such as aesthetics and intention (Fig. 1).

More importantly, vibrations from the violin body and the bowed strings (via the bow) are used to provide the player-musician with extra-auditory cues that contribute to the perception of the sound, so that the player can assess their interaction with the instrument crossmodally, often supplementing auditory feedback with vibrotactile signals to better control the played sound (Askenfelt and Jansson, 1992; Chafe, 1993; Woodhouse, 1993; Obata and Kinoshita, 2012). Recent findings particularly illustrate that vibrotactile feedback at the left hand of the violinist can make the played sound perceived as "richer" and "louder" (Wollman *et al.*, 2014a). Indeed, vibrotactile cues are perceptually relevant not only to violin performers but also to non-violinist musicians (Galembo and Askenfelt, 2003; Giordano *et al.*, 2010; Eitan and Rothschild, 2011; Fontana *et al.*, 2014; Paté *et al.*, 2015). A biomechanical explanation for the crossmodal sensation of sound by the ear and the skin during musical performance may rely on structural similarities both in the respective stimuli (what is heard and what is felt both result from the same vibrations) and the particular mechanoreceptors involved (Marks *et al.*, 1986; Orr *et al.*, 2006).

B. A framework for the perceptual evaluation of violins

The lexicon musicians use to describe characteristics of the violin sound and playing experience (rich, mellow, resonant, responsive, clear, balanced, etc.) illustrates the extent to which perceived variations in the structure of acoustic and haptic stimuli generated by the same source (violin), and consequently microconcepts of quality perception, are very subtle. In some cases, the same physical phenomenon can give rise to different concepts (e.g., well articulated notes make a violin perceived as both clear and responsive). Conceptualization structures further rely on the variations in expertise and experience of the different individuals (Bensa *et al.*, 2005). Yet the broader seman-

FIG. 2. Placed approximately here.

tic categories emerging from these sensory descriptions remain common across performers with diverse musical profiles, reflecting a shared perception of physical parameter patterns that allows us to form a number of hypotheses for understanding psychoacoustical relationships.

Accordingly, Fig. 2 presents a model that may explain how the dynamic behavior of a violin relates to its quality in the mind of the player. Body vibrations, driven by the bowed string and shaped by the physical dimensions of the instrument (i.e., size, weight, action), shape in turn the spectrum of the radiated sound. The quality of the spectral content is then processed in terms of number of partials (conceptualized as RICHNESS) and distribution of energy across the spectrum during sustain (conceptualized as TEXTURE), total energy during sustain and release (conceptualized as RESONANCE and PROJECTION), audible artifacts during transients (conceptualized as CLARITY), and how these differ from note to note across the four strings of the instrument (conceptualized as BALANCE). The bowed string and vibrating body system further contributes to the quality profile through the amount of felt vibrations in the left hand, shoulder and chin (conceptualized as RESONANCE); through assessing the offset (speed) and amount (ease) of reactive force (conceptualized as RESPONSE) from the body in the right hand (through the bow) with respect to the quality and quantity of the heard and felt vibrations; and through comparing these between notes and strings (conceptualized as BALANCE).

This is a tentative model and several issues would need to be clarified empirically. Can such standard acoustical measurements as a violin's input admittance or radiation profile capture everything significant about the spectrotemporal structure of the produced sound, or about the reactive force and vibration levels felt by the player? If yes, in what ways can this information be extracted (e.g., Elie *et al.*, 2014; Fréour *et al.*, 2015)? Together with the illustration of the violin-violinist system of interactions shown in Fig. 1, this model is proposed as a first step toward a framework for the perceptual evaluation of violins, grounded in psycholinguistic evidence of how musicians conceptualize sound and playing qualities.

C. Implications for the perception of timbre

The use of words associated with texture, mass, and luminance to describe structural attributes of the sound indicates what type of semantic dimensions may explain the perception of timbral nuances in violin sound. Very similar semantic resources are commonly observed in verbal descriptions of instrument-specific timbre by experts, for example the trombone (Edwards, 1978), pipe organ (Rioux and Västfjäll, 2001; Disley and Howard, 2004), saxophone (Nykänen and Johansson, 2003), classical guitar (Traube, 2004; Lavoie, 2013), acoustic piano (Cheminée, 2009; Bernays and Traube, 2011), violin (Fritz *et al.*, 2012a; Zanoni *et al.*, 2014), and electric guitar (Paté *et al.*, 2015). They are also evident in verbalized impressions of vocal (Garnier *et al.*, 2007), percussive (Brent, 2010) and electroacoustic (Grill, 2012) timbre, but also in social tagging of "polyphonic timbre" or songs (Ferrer and Eerola, 2011). The recent work of Zacharakis *et al.* (2015) demonstrated that the texture-mass-luminance dimensions may provide a general semantic framework for timbre across different types of musical and non-musical sounds, as well as between different linguistic and cultural groups (the study was conducted with native Greek and English listeners).

The metaphorical nature of the lexicon used to describe timbral qualities of the played sound shows that violinists are not familiar with describing sound as a sensory experience in an objective, quantitative way and share little knowledge about the perceptual dimensions of sound. Instead, they conceptualize and communicate sound qualities through different sensory domains—for instance, a sound "felt" as soft, velvety, or strong (touch); "seen" as bright, clear, or big (vision); and "tasting" as sweet, raw, or *acide* (gustation). These metaphorical linguistic structures are central to the process of conceptualizing timbre by allowing the musician-listener to meaningfully experience and communicate subtle sonic variations in terms of other domains (Lakoff and Johnson, 2003; Wallmark, 2014). As with semantic resources, such cross-domain metaphors are common in sensory descriptions of musical as well non-musical sound experience (the reader is referred to the works cited in the previous paragraph). Furthermore, they exemplify a particular aspect of human perception: we make many synaesthetic-like associations between experiences presented in different sensory modalities, such as matching low-pitched sounds to umami and bitter tastes (Crisinel and Spence, 2010) as well as to big sized objects (Bien *et al.*, 2012). Psychophysiological evidence specifically suggests that timbral cues can activate attributes or concepts borrowed from other modalities (Schön *et al.*, 2009; Grieser-Painter and Koelsch, 2011).

D. Influence of task and sample constraints

Two final considerations of general methodological significance are necessary about the interpretation of these results and thus their importance. First, the analysis presented here adopted a situated approach: semantic categories of violin quality were elicited from spontaneous descriptions of preference judgments by experienced violinists collected in playing tests. We took special caution in designing experimental tasks that are empirically valid but also musically meaningful to the violinist. Rather than simply listening to and verbally tagging recorded sounds, violin players thus described the different quality characteristics they perceived inside a more involved and familiar experience.

RESONANCE was the second most frequently emerging semantic category in experiment 1, but in experiment 2 such expressions were less prominent. A methodological difference between the two experiments could explain this difference. Whereas experiment 1 involved perceptual judgments based on overall preference, in experiment 2 players evaluated violins on five specified attributes—ease of playing, response, richness, dynamic range, balance—none of which was explicitly related to the intensity of the sound. It thus seems plausible that the type of task at hand may affect how quality dimensions are negotiated.

Descriptions of sound PROJECTION were the least recurrent in both experiments. To a certain extent, in experiment 2 this might have been imposed by the design of the task similarly to the case of RESONANCE. However, the very small proportion of PROJECTION in the corpus of experiment 1 may generally reflect a low cognitive priority for this attribute as a result of the difficulty in judging reliably how well the sound is transmitted across the performance space solely by playing the violin—but still musicians consider this an attribute important enough to evaluate even if by estimation (Loos, 1995; Fritz *et al.*, 2014).

Second, we expect that there are variations of the language (i.e., the specific lexicon and its meaning) used by musicians from place to place (sometimes resulting from a strong influence by one or more particular teachers in an area). The present analysis might thus be biased toward a verbal tradition specific to the Montreal region. Nevertheless, this research provides a resource that should be consulted by any researchers planning to conduct perceptual studies of violin quality (i.e., when designing the language used in their experiments).

V. CONCLUSIONS

The overall goal of the research presented here is to better understand how musicians evaluate violins within the wider context of finding relationships between measurable vibrational properties of instruments and their perceived qualities. Contrary to the typical approach of beginning with a physical hypothesis based on structural dynamics measurements or audio feature extraction, a method based on psycholinguistic inferences (Dubois, 2000) was used to identify and categorize concepts of violin quality emerging in spontaneous verbal descriptions collected in two experimental studies, whereby a total of 29 musicians played and evaluated different violins and subsequently justified their choices in free verbalization tasks. This method has been previously applied to other instruments such as the piano (e.g., Bellemare and Traube, 2005) and the guitar (e.g., Paté *et al.*, 2015), advancing our understanding of how their sound and playing characteristics are perceived by performers. This paper reports the first extensive psycholinguistic investigation of violin quality perception, expanding on an earlier study with only 3 musicians by Fritz *et al.* (2010).

The semantic patterns-categories underlying the found concepts can be seen as a first step in translating the semantics of violinists' expressions into perceptually meaningful descriptors of violin quality. Importantly, they demonstrate that violin players with different levels of experience and expertise share a common framework for differentiating the sensory meanings of auditory and haptic information. A schematic depiction of this framework is proposed, which can be useful for future studies aimed at assessing violin quality characteristics (see Fig. 1 and 2). The emergence of shared conceptualization structures between musicians suggests, in line with our previous findings (Saitis *et al.*, 2012, 2015), that interindividual differences in the preference for violins originate from variations in the perception of different violin attributes, rather than from disagreement about what properties a preferred violin possesses.

Specifically considering the relevance of playability aspects in overall violin preference judgments, more research would be needed on how to describe and assess the control of bowing parameters and their coordination, which allow the player to access the high musical expressivity of a particular instrument. Recent evidence suggests a bowing-based link between the quality of a violin and its range of quiet to loud playing (Sarlo *et al.*, 2016). Improving our understanding of how violinists vary bowing parameters to shape their desired sound could help tease apart the effects of individual playing skills on quality evaluation.

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NOTES

[1] In the open string region, 196–660 Hz, the frequency response of the violin body as measured at the bridge is characterized by the presence of five resonances that are sufficiently separated from the adjacent modes and hence easily identifiable: A0, a Helmholtz-type resonance with $f_{A0} \approx 280$ Hz that radiates strongly through the f-holes; CBR, the lowest corpus mode with $f_{CBR} \approx 400$, two-dimensional flexure, usually a weak radiator; A1, a higher cavity mode with $f_{A1} \approx 1.7 \times f_{A0}$ that sometimes radiates strongly but is usually a weak radiator; $B1^{-}$ (mainly motion of top plate) and $B1^{+}$ (two-dimensional flexure), the first strongly-radiating corpus bending modes with $f_{B1^-} \approx 480$ and $f_{B1^+} \approx 550$, also radiating strongly through the sound holes.

[2] The complete original verbal responses are found in the appendix of the first author's doctoral dissertation (Saitis, 2013, pp. 145–172).

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TABLE I. Musical profile of participants and semantic categories they used.

		Musical profile			Semantic categories							
		Practice (yrs)	Skill	Style of music	Ri	Te	Pl	Cl	Re	Pr	Ba	In
Experiment 1	1	60	Professional	Classical			✗	✗			✗	✗
	2	30	Amateur	Classical	✗	✗	✗		✗		✗	✗
	3	25	Professional	Classical	✗	✗	✗	✗	✗	✗	✗	✗
	4	46	Professional	Classical, Baroque, Folk, Jazz	✗		✗		✗	✗		✗
	5	31	Professional	Classical, Folk, Modern	✗	✗	✗		✗	✗	✗	✗
	6	32	Professional	Classical, Baroque	✗	✗	✗	✗	✗	✗	✗	✗
	7	34	Professional	Classical	✗	✗	✗	✗	✗	✗	✗	✗
	8	25	Professional	Classical, Baroque	✗	✗	✗	✗	✗	✗	✗	✗
	9	15	Amateur	Classical, Baroque, Folk, Modern	✗	✗	✗	✗	✗		✗	✗
	10	27	Professional	Classical, Baroque	✗	✗	✗	✗	✗		✗	✗
	11	16	Amateur	Classical, Folk	✗	✗	✗	✗	✗		✗	✗
	12	11	Amateur	Classical, Folk	✗	✗	✗	✗	✗		✗	✗
	13	17	Amateur	Classical, Baroque, Folk, Jazz	✗	✗	✗		✗		✗	✗
	14	18	Professional	Classical, Folk	✗		✗		✗		✗	✗
	15	25	Professional	Folk	✗	✗	✗	✗	✗	✗		✗
	16	45	Professional	(no style reported)			✗		✗	✗	✗	✗
	17	20	Amateur	Classical, Baroque	✗	✗	✗		✗	✗	✗	✗
	18	15	Amateur	Classical	✗	✗	✗		✗	✗	✗	✗
	19	21	Professional	Classical	✗	✗	✗	✗		✗	✗	✗
	20	16	Professional	Classical, Folk	✗	✗	✗	✗	✗	✗	✗	✗
Experiment 2[a]	1	12	Professional	Classical		✗	✗				✗	
	2	30	Professional	Folk, Jazz, Tango			✗		✗			✗
	3	21	Professional	Classical		✗	✗	✗			✗	
	4	25	Professional	Classical			✗			✗		✗
	5	15	Professional	Classical	✗	✗	✗		✗			
	6	46	Professional	Classical, Baroque, Folk, Jazz			✗					✗
	7	26	Professional	Classical		✗	✗		✗			
	8	17	Amateur	Classical, Folk	✗	✗	✗		✗			
	9	16	Professional	Classical	✗			✗				✗
	10	16	Professional	Classical, Folk	✗	✗	✗	✗				
	11	20	Professional	Classical, Baroque	✗		✗			✗		✗
	12	25	Professional	Classical	✗		✗		✗			✗
	13	16	Amateur	Classical, Baroque								✗

[a] Participants 7, 4, and 11 are the same as 4, 19, and 20 in experiment 1, respectively.

TABLE II. Violins used in the experiments. Ordered by price.

	Violin	Origin	Luthier[a]	Year	Price
Experiment 1	A	France	Silvestre	1840	$65K
	B	Italy	Cavallini	1890	$35K
	C	Canada	-	2010	$16K
	D	Canada	-	2010	$13K
	E	Canada	-	1976	$10K
	F[c]	Germany[b]	Unknown	Unknown	$8K
	G	France	Apparut	1936	$6K
	H	China	-	2010	$1.3K
Experiment 2	A	Italy	Gagliano	1770–75	$250K
	B	Italy	Storioni	1799	$44K
	C	Germany	Fisher	1787	$22K
	D	Italy	Sderci	1964	$20K
	E	France	Kaul	1933	$20K
	F	France	-	2009	$17K
	G	France	Guarini	1877	$11K
	H[c]	Germany	Unknown	Unknown	$8K
	I	Canada	-	2005	$6K
	J	China	-	2006	$2K

[a] Names of living luthiers are not provided for confidentiality purposes.
[b] Based on a luthier's informal appraisal, as there is no information regarding the make and age of this violin.
[c] This is the same violin.

TABLE III. Emerging semantic categories of violin quality concepts (French verbalizations are reported in `verbatim`).

Semantic category	Microconcepts (+)	Microconcepts (−)	Type of attribute	Object of evaluation
RICHNESS	rich (32), [with many] colors (10), [with many] harmonics (10), [with many] overtones (9), deep (9), full (5), complex (3), `expressif` (2), thick, different sound qualities, different tonalities, different shades, emotive possibilities, to have substance, to have a weight behind it	hollow (3), colorless, simple, dry, `sourd`, `inexpressif`, limited color palette, muted overtones	structural	sound
TEXTURE	warm (15), bright (9), mellow (8), sweet (6), silky (6), smooth (5), round (5), dark (5), velvety (3), singing (3), soft (2), golden, `coupant dans le son`, a viola type of sound	tinny (9), harsh (6), bright (6), raw (3), rough (3), shrill (2), strident (2), `acide` (2), `grossier`, stringy, grating, hard edge to the sound, mechanic	structural	sound
RESONANCE	resonant (28), powerful (19), open (7), vibrant (5), strong (5), `puissance` (4), volume (4), loud (4), sustain (3), responsive (2), ringing (2), free (2), big (2), bright, brilliant, present, liveliness, sonority, unconstrained, unrestrained, `ample`, to carry a lot of sound, good sound production, `une voix qui ‘‘parle"`, `repondre facile proche de nous`, to last after the bow is lifted	muted (9), flat (4), muffled (3), weak (3), compressed (2), tight (2), `petit` (2), `éteint` (2), `étouffé` (2), `ferme`, strangled, squeezed, thin, dormant, constrained, controlled, `terne`, `nasillard`, `mince`, to lack ability, to get trapped inside, `n'avoir aucun tonus`, as if there is something inhibiting the sound	structural & vibrotactile	sound
PROJECTION	projection (28), to carry (2), `porter` (2), to fill [a space] (2), to cut across a hall, to travel, `voyager sans forcer`	weak, to sound shaved on the top, `empecher de voyager`	spatial	sound
RESPONSE	easy to play (66), responsive (23), broad dynamic range (14), light (11), comfortable (8), quick (8), playability (7), flexible (6), ability to create different timbres (6), versatile (4), low action (2), predictable (2), `maniable` (2), liberty (2), `solidité`, cushioned, convenient to handle, enough room for control, reflexible, well-adjusted, small, `touche agréable`, fit bridge, to feel a healthy contact with the bow on the string, `répondre au quart de tour`, to give a lot back, to take a lot of weight from the bow, to stand up to what the player gives	hard to play (5), heavy (3), uncomfortable (3), more effort (3), difficult to play (2), slow (2), missing of the tuning (2), bulky (2), big, `gros`, awkward, rigid, too light, labored vibrato, big neck, to fight with the instrument [to produce the desired sound]	proprioceptive	violin-player interaction
CLARITY	clear (29), pure (3), to speak well (3), focus (3), clean (2), `consonnes articules` (2), direct, straightforward, defined, bright, to articulate well, the way notes lead into the next, `l'ouverture du son`	scratchy (10), wolf tone (7), buzzing (7), muddy (5), whistles (3), sore throat (3), hoarse (2), blurry (2), sand (2), noise (2), kettle effects, metallic, tinny, unrecognizable, to break	structural	sound
BALANCE	even (20), balanced (11), `égal` (8), consistent (6), stable (2), `l'equilibre entre les cordes` (2), relation between strings (2), `focus`, strings harmonized best, string differentials, equal	uneven (4), `inegal`, to not feel as good on the lower strings	structural & proprioceptive	sound & violin-player interaction
INTEREST	beautiful (18), good (8), quality (8), color (7), interesting (6), nice (6), unique (4), pleasant (4), timbre (3), enjoyable to play (3), great (3), pleasing (2), to inspire (2), basic (2), natural (2), to have character, perfect, rare, `complet`, fascination, satisfaction, preference, to appeal, fun to play, to feel right, to feel great, a sound that I look for	irritating (2), unpleasant (2), `sans interet`, boring, overbearing, generic, `impersonnel`, to not like, the sound is like a poor quality recording	affective	sound & violin-player interaction

TABLE IV. Distribution of categories within and across responses to questions (N = total units; # = coded units; % = proportion).

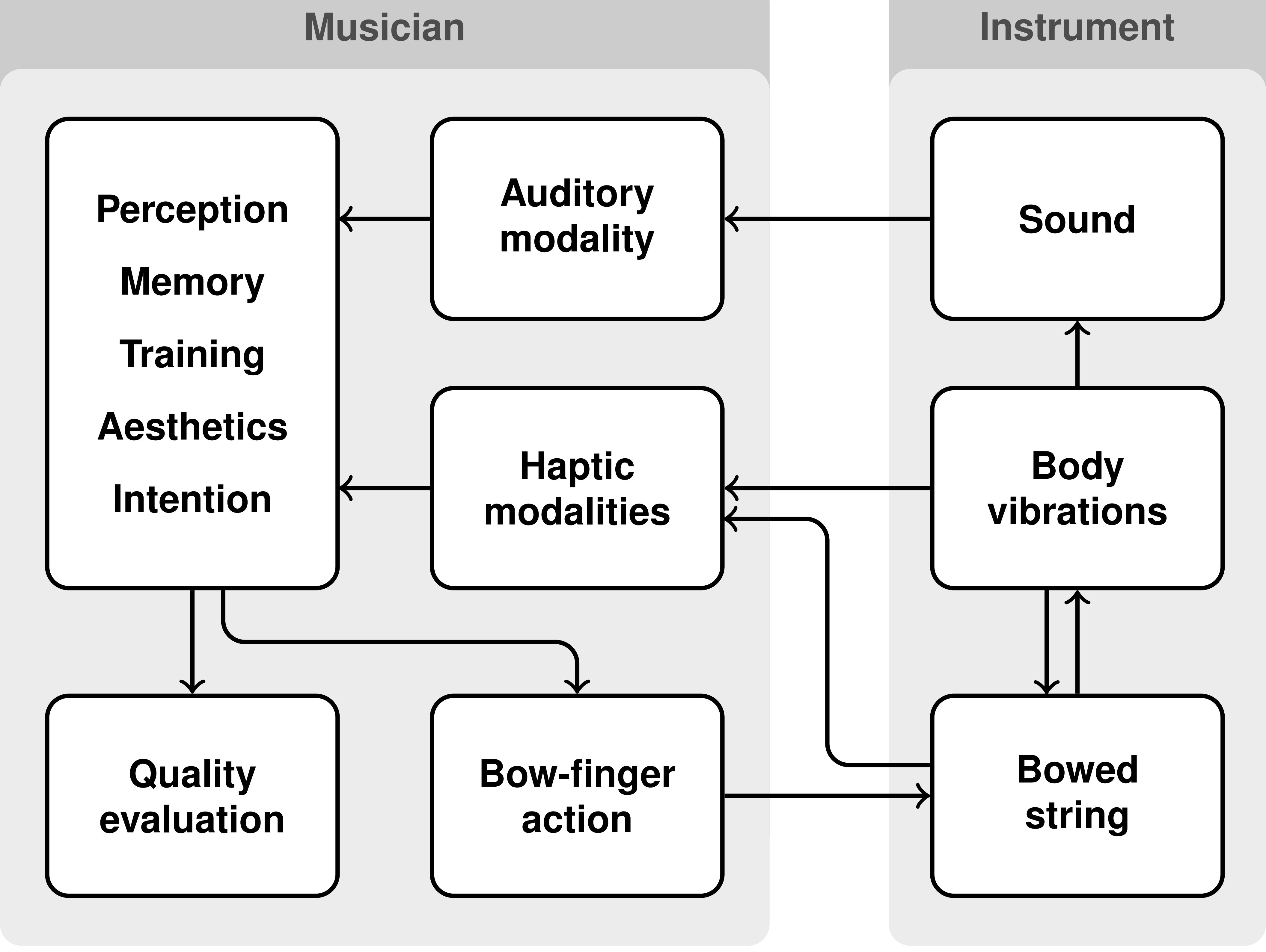
	Experiment 1										Experiment 2	
	A1 ($N = 240$)		A2 ($N = 189$)		A3 ($N = 169$)		B ($N = 168$)		ALL ($N = 766$)		($N = 62$)	
	#	%	#	%	#	%	#	%	#	%	#	%
RICHNESS	20	8	28	15	11	7	22	13	81	11	8	13
TEXTURE	13	5	36	19	23	14	23	14	95	12	8	13
RESONANCE	46	19	17	9	45	27	24	14	132	17	5	8
PROJECTION	12	5	9	5	8	5	10	6	39	5	2	3
RESPONSE	66	28	45	24	29	17	46	27	186	24	19	31
CLARITY	26	11	13	7	26	15	14	8	79	10	8	13
BALANCE	29	12	12	6	9	5	13	8	63	8	2	3
INTEREST	28	12	29	15	18	11	16	10	91	12	10	16

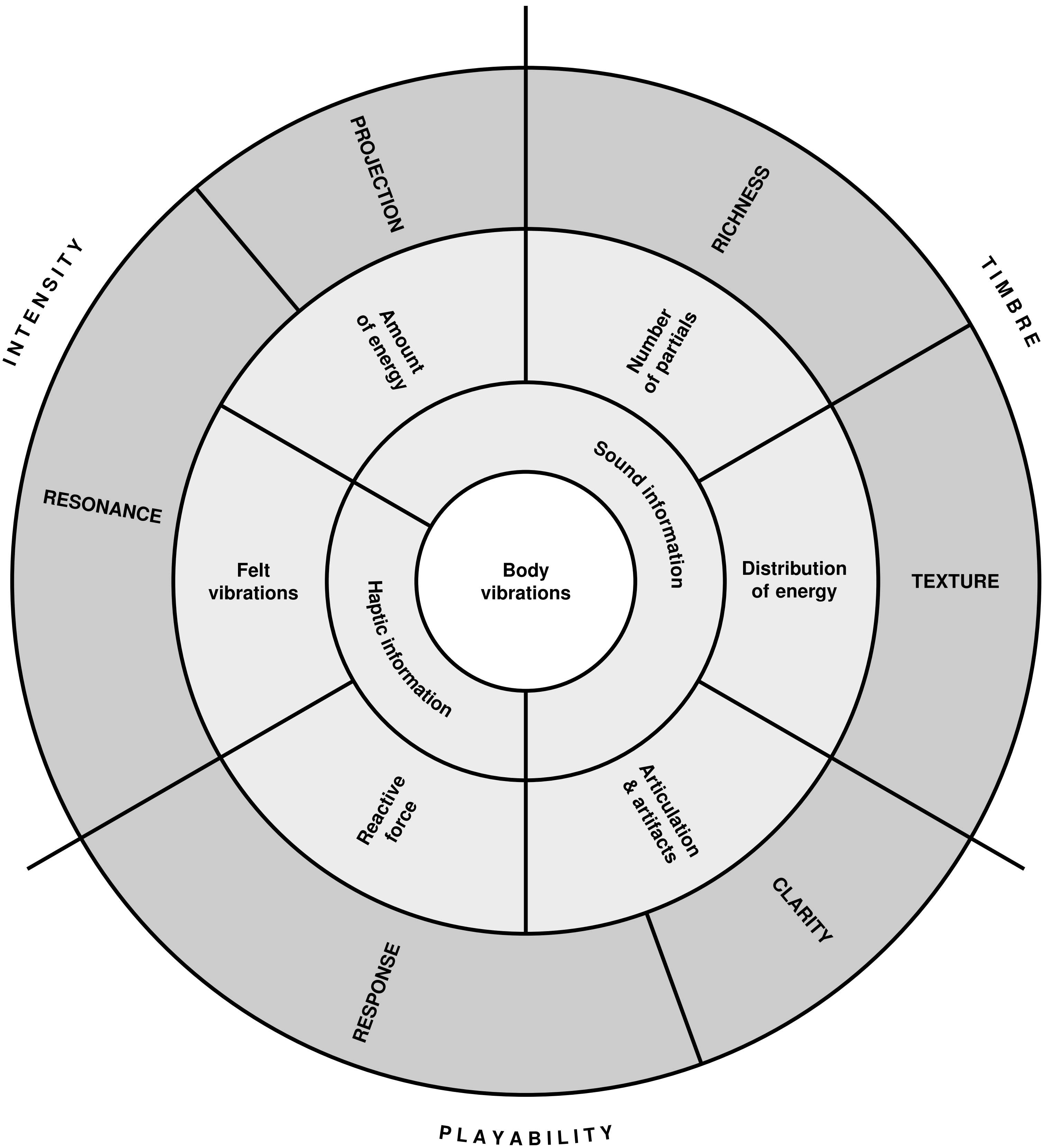
TABLE V. Distribution of verbal units by object of reference and directed attribute (N = total units; # = coded units; % = proportion).

	Experiment 1 ($N = 766$)				Experiment 2 ($N = 62$)			
	Sound # = 546 % = 71		Interaction # = 220 % = 29		Sound # = 38 % = 61		Interaction # = 24 % = 39	
	#	%	#	%	#	%	#	%
Structural	388	71			29	76		
Spatial	39	7			2	5		
Vibrotactile	39	7			1	3		
Affective	80	15	11	5	6	16	4	17
Proprioceptive			209	95			20	83

Fig. 1 Musician–instrument interaction in violins. Quality evaluations and affective reactions are elaborated on the basis of both auditory and haptic cues (sensory factors) filtered through previous experience and interpretation processes (non-sensory contextual factors). Adapted from Papetti (2013, Fig. 1).

Fig. 2 From body vibrations to semantic categories: a model describing how the dynamic behavior of a violin relates to its quality in the mind of the musician.


Musician
Instrument
Perception
Memory
Training
Aesthetics
Intention
Auditory modality
Sound
Haptic modalities
Body vibrations
Quality evaluation
Bow-finger action
Bowed string


INTENSITY
TIMBRE
PLAYABILITY
PROJECTION
RICHNESS
RESONANCE
TEXTURE
RESPONSE
CLARITY
Amount of energy
Number of partials
Felt vibrations
Distribution of energy
Reactive force
Articulation & artifacts
Sound information
Haptic information
Body vibrations

Rebuttal letter

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