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SEMANTIC DIMENSIONS OF SOUND MASS MUSIC: MAPPINGS BETWEEN PERCEPTUAL AND ACOUSTIC DOMAINS

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WE COMBINE PERCEPTUAL RESEARCH AND ACOUSTIC analysis to probe the messy, pluralistic world of musical semantics, focusing on *sound mass* music. Composers and scholars describe sound mass with many semantic associations. We designed an experiment to evaluate to what extent these associations are experienced by other listeners. Thirty-eight participants heard 40 excerpts of sound mass music and related contemporary genres and rated them along batteries of semantic scales. Participants also described their rating strategies for some categories. A combination of qualitative stimulus analyses, Cronbach's alpha tests, and principal component analyses suggest that cross-domain mappings between semantic categories and musical properties are statistically coherent between participants, implying non-arbitrary relations. Some aspects of participants' descriptions of their rating strategies appear to be reflected in their numerical ratings. We sought quantitative bases for these associations in the acoustic signals. After attempts to correlate semantic ratings with classical audio descriptors failed, we pursued a neuromimetic representation called spectrotemporal modulations (STMs), which explains much more of the variance in semantic ratings. This result suggests that semantic interpretations of music may involve qualities or attributes that are objectively present in the music, since computer simulation can use sound signals to partially reconstruct human semantic ratings.

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Key words: musical semantics, contemporary music, sound mass, spectrotemporal modulations, cross-domain mappings

A SIGNIFICANT CHALLENGE FOR ANY ACCOUNT of musical semantics is the problem of *plurality*: the well-known fact that the same music can give rise to different interpretations. As composer Witold Lutosławski described it:

The variety of perception greatly increases when we start to penetrate . . . the realm of associations, that is, the extramusical interpretations of sensations the work produces. The differences in the perception of music in this layer (if it exists at all) are, of course, the greatest, and even diametrically opposed. Sometimes we encounter amazingly inconsistent relations . . . (2007, pp. 92–93)

For some, including Lutosławski, the problem of plurality is sufficient cause to avoid questions of musical semantics altogether, or to consider music an “asemantic art” (pp. 102–103). But to take this position is to ignore a pervasive aspect of musical experience. As Huovinen and Kaila (2015) point out, “there appears to be a large consensus that music can importantly function as a carrier of extramusical meaning . . . the implication is not merely that music might help any personally significant imagery to emerge from one's psyche . . . but that it is the *music* that means—or is taken to mean—something extramusical” (p. 217). Discussions among concertgoers following performances, instructions to musicians from their teachers and conductors, and descriptions of artistic aims by many composers and performers are chock-full of metaphorical imagery, as, we would wager, are the reader's reflections on their own musical experiences. In this paper, we combine perceptual research and acoustic analysis to probe the messy, pluralistic world of musical semantics, focusing on recent music by composers including Lutosławski and his contemporaries. As we aim to demonstrate, even if listeners may frequently differ in their interpretations of music, it does not follow that semantic associations are arbitrary or baseless, that there is no intersubjective consistency between them, or that they cannot be productively studied.

Music scholarship has recently witnessed increasing interest in semantic associations, with a robust and growing body of empirical research. To list but a few examples: studies have established intersubjective consistency in verbal descriptions of musical instrument qualia (Reymore & Huron, 2018, 2020), consistent application of descriptive terminology for musical instrument timbres by authors of orchestration treatises (Wallmark, 2019), cognitive-linguistic bases for

timbre semantics (Wallmark & Kendall, 2018), analogical bases for descriptions of musical instrument timbres (Traube & Lavoie, 2008; Traube, Bernays, & Bellemare, 2008), acoustical bases for timbre semantics (Saitis, 2019), interlanguage studies of semantic, acoustic, and perceptual dimensions of musical timbre (Zacharakis & Pasiadis, 2016; Zacharakis, Pasiadis, & Reiss, 2012, 2015), and semantic or narrative accounts of specific repertoires including commercial production music (Huovinen & Kaila, 2015) and orchestral music (Margulis, 2017). Little research to date, however, has focused on semantics in contemporary or recent music. In this paper, we focus on *sound mass* music, which shifts focus away from discrete pitch and rhythm and onto timbre and texture. We define sound mass as a perceptually homogeneous and dense auditory unit integrating multiple sound events or components while retaining an impression of multiplicity (Noble & McAdams, 2020). Although musical sound masses may be acoustically complex, they are perceptually simple because they resist perceptual segmentation in one or more parameters (e.g., pitch, rhythm, timbre; for a more detailed discussion, see Noble, 2018, pp. 5–8). We believe this kind of music is a particularly interesting object of semantic study, for several reasons. By emphasizing musical parameters that have traditionally been relegated to a “secondary” role in musical practice and scholarship, sound mass invites semantic associations through attributes other than those traditionally assumed to be the primary bearers of meaning (e.g., melodies, motifs, harmonic progressions). Since many listeners are unfamiliar with sound mass music, their semantic associations may reflect metaphorical or analogical reasoning rather than culturally enshrined interpretations such as *topoi* (Monelle, 2000): that is, semantic associations in this music may plausibly reflect active mappings between attributes of the sound signal and attributes of semantic domains, rather than conventionalized responses to symbolic codes. There may still be topical associations at work in listeners’ associations of contemporary music, proceeding chiefly from their exposure to this kind of music in the context of film scores, especially soundtracks for horror, science fiction, fantasy, and fairy tale movies. Nevertheless, even if topical associations are not completely absent from listeners’ interpretations of contemporary music, they may at least be less developed and therefore less constraining than in other, more familiar kinds of music. In the terminology of the “career of metaphor” hypothesis of Gentner, Bowdle, Wolff, and Boronat (2001), semantic associations of contemporary music may be more like *novel*

metaphors, whereas musical *topoi* are more like *conventional* metaphors.

Composers and scholars describe sound mass with many vivid and evocative terms (see Noble, 2018, pp. 103–119). For example (emphases added):

“there is [in my music] a state of supersaturated polyphony, with all the ‘*crystal* culture’ in it” (Ligeti, Várnai, Häusler, & Samuel, 1983, p. 14)

“I proposed a world of sound-masses, vast groups of sound-events, *clouds*, and *galaxies* governed by new characteristics such as density . . .” (Xenakis, 1971, p. 182)

“With the unfolding of the mass, a *kaleidoscope* of sonic hues is projected in an ever-varying transformation . . .” (Reiprich, 1978, p. 180)

“The resulting textures are always dynamically changing and range from *swarms* of relatively isolated sound events to fused sound masses of great internal complexity, much like environmental sound generally and *water* sound in particular.” (Truax, 1990, p. 123)

Some of these semantic domains, such as *water*, may relate to music through acoustic similarity (that is, the music might employ actual recordings of water, or otherwise mimetically suggest *water* sounds), while other domains, such as *clouds* or *kaleidoscope*, must relate in a more abstract way, since they have no associated sound images that the listener might relate to the music. Addressing in detail just how metaphorical mappings might work in these conceptually different situations is a thorny theoretical issue that is beyond the scope of this empirical study: this will be the subject of a future paper. For our purposes here, we assume the psychological reality of mappings between musical and semantic domains, and we assume that those mappings may be based on acoustic similarity or on other types of relations.

Given these premises, we sought to answer the following questions:

- (1) Is there coherence between listeners in their semantic associations with sound mass music?
- (2) Are the semantic associations used in the discourse of sound mass composers and scholars relevant to the experience of other listeners?
- (3) Can such semantic associations be explained in terms of mappings between acoustic attributes and attributes of semantic domains?
- (4) Do listeners respond similarly to mappings based in acoustic similarity and mappings based on more abstract affinities?

Experiment

To attempt to answer these questions, we conducted an experiment at the Music Perception and Cognition Lab at McGill University, in which participants heard 40 excerpts of sound mass music and related contemporary genres, and rated them along batteries of semantic scales using descriptive terminology taken from the writings and interviews of composers and scholars. Excerpts were selected from the pieces listed in Table 1 (complete documentation in Appendix A, scores and recordings listed in the References).

Pieces were selected to cover many different approaches to fusion-based aesthetics, providing a diverse range of attributes for potential cross-domain mapping. Participants rated each excerpt along batteries of semantic scales in three blocks (Table 2), selected from the published literature on sound mass and based on several

criteria. We sought to include terms that appeared frequently in the literature (e.g., dense, static) and terms used by important sound mass composers (e.g., galaxies for Xenakis, crystals for Ligeti). Overall, the list aimed to cover examples from seven categories identified in Noble (2018) for types of metaphors used in sound mass discourse: spatial, material, behavioral, cross-modal, naturalistic, technological, and surrealistic. We sorted the terms into blocks based on the grammatical form in which they appear most commonly (adjectives in Block 2, nouns in Block 3), with a separate block for terms that appear frequently in published definitions of sound mass (Block 1). Additionally, participants were given the option to add a category in each block if they wished to report an association not present in the provided lists.

There was no presumption of one-to-one or “correct” correspondences between the semantic scales and the musical excerpts used in the experiments. Excerpts were

TABLE 1: *Compositions From Which Stimuli Were Extracted for the Experiment*

Composer	Title	Instrumentation/Media	Date of Composition
Iannis Xenakis	<i>Metastaseis</i>	orchestra	1953-1954
Iannis Xenakis	<i>Pithoprakta</i>	string orchestra	1955-1956
Witold Lutosławski	<i>Musique Funèbre</i>	string orchestra	1954-1958
Krzysztof Penderecki	<i>Threnody to the Victims of Hiroshima</i>	string orchestra	1960
György Ligeti	<i>Atmosphères</i>	orchestra	1961
Witold Lutosławski	<i>Jeux Vénitiens</i>	orchestra	1961
Krzysztof Penderecki	<i>Polymorphia</i>	string orchestra	1961
Witold Lutosławski	<i>Trois Poèmes d'Henri Michaux</i>	orchestra and choir	1962-1963
György Ligeti	<i>Requiem</i>	orchestra and soloists	1965
György Ligeti	<i>Volumina</i>	organ	1967
Witold Lutosławski	<i>Symphony No. 2</i>	orchestra	1965-1967
Veljo Tormis	<i>Jaanilaulud</i>	choir	1967
Karlheinz Stockhausen	<i>Stimmung</i>	amplified voices	1968
György Ligeti	<i>Double Concerto</i>	flute, oboe, and orchestra	1972
Gérard Grisey	<i>Partiels</i>	chamber orchestra	1975
Witold Lutosławski	<i>Mi-parti</i>	orchestra	1975-1976
Henryk Górecki	<i>Symphony No. 3</i>	orchestra and soprano	1976
Iannis Xenakis	<i>Mycenae Alpha</i>	electronics (UPIC)	1978
Toru Takemitsu	<i>Asterism</i>	orchestra	1979
Jonathan Harvey	<i>Mortuos Plango, Vivos Voco</i>	electronics	1980
Witold Lutosławski	<i>Double Concerto</i>	oboe, harp, and chamber orchestra	1980
Francis Dhomont	<i>Points de Fuite</i>	electronics	1982
Jean-Claude Risset	<i>Sud B</i>	electronics	1985
Barry Truax	<i>Riverrun</i>	electronics	1986
Trevor Wishart	<i>Vox 5</i>	voices and electronics	1986
Barry Truax	<i>The Wings of Nike</i>	electronics	1987
Kaija Saariaho	<i>Du cristal</i>	orchestra	1989
Barry Truax	<i>Pacific</i>	electronics	1990
Philippe Hurel	<i>Six Miniatures en Trompe-l'œil</i>	chamber orchestra	1991/1993
Stéphane Roy	<i>Mimetismo</i>	guitar and electronics	1992
Stéphane Roy	<i>Crystal Music</i>	electronics	1994
Georg Friedrich Haas	<i>Hyperion</i>	orchestra	2006
Franck Bedrossian	<i>Tracés d'Ombres</i>	string quartet	2007
Robert Normandeau	<i>Clair de Terre</i>	electronics	1999, 2009

TABLE 2: *Semantic Scales Rated in Experiment*

Block 1	Block 2	Block 3
<i>Fusion</i>	<i>Volatile</i>	<i>Gas</i>
<i>Density</i>	<i>Atmospheric</i>	<i>Liquid</i>
<i>Complexity</i>	<i>Busy</i>	<i>Solid</i>
<i>Homogeneity</i>	<i>Static</i>	<i>Clouds</i>
	<i>Formless</i>	<i>Wind</i>
	<i>Impenetrable</i>	<i>Water</i>
	<i>Voluminous</i>	<i>Webs</i>
	<i>Kaleidoscopic</i>	<i>Galaxies</i>
		<i>Crystals</i>
		<i>Machinery</i>
		<i>Herds/Crowds/Swarms</i>

selected to present a wide variety of sonic attributes that might plausibly map onto semantic domains. We expected to observe correlations between musical or acoustic attributes in the excerpts and participants' ratings for the semantic scales, sometimes explicable in terms of acoustic similarity (for example, the excerpt from *Vox 5*, which samples the sound of buzzing bees, would probably be rated highly for Herds/Crowds/Swarms) and sometimes in terms of abstract affinities (for example, the excerpt from *Threnody to the Victims of Hiroshima*, which consists of a loud quarter-tone cluster filling a wide range of the audible spectrum, would probably be rated highly for Impenetrable). Finally, we hypothesized that excerpts with similar musical or acoustic properties would invite similar mappings. However, we understood that our ability to draw strong conclusions would be limited by the complex nature of the stimuli (since it is difficult to know to which musical attributes participants attend) and by the polysemic nature of the terminology used in the semantic scales (since it is difficult to know which connotation(s) provide the basis for cross-domain mapping).

METHOD

Participants. Thirty-eight participants (24 female) between 18 and 50 years of age ($M = 24.9$, $SD = 6.0$) completed the experiment. Twenty-one participants self-identified as professional musicians and reported an average of 11.7 years of training on a primary instrument ($SD = 5.0$) with additional training in aural skills ($M = 4.7$, $SD = 4.5$), music analysis ($M = 2.4$, $SD = 2.2$), and music history ($M = 3.2$, $SD = 2.5$). The remainder did not consider themselves professional musicians and reported an average of 0.8 years of childhood or casual training on an instrument ($SD = 2.3$) and no training in aural skills, harmony, analysis, and music history. Nine of the musicians and none of the

nonmusicians indicated familiarity with sound mass music. All participants were fluent in English. Prior to completing the experiment, all participants passed a pure-tone audiometric test using a MAICO MA 39 (MAICO Diagnostic GmbH, Berlin, Germany) audiometer at octave-spaced frequencies from 125 Hz to 8 kHz (ISO 389-8, 2004; Martin & Champlin, 2000) and were required to have thresholds at or below 20 dB HL to proceed. All participants completed the same task, and each was paid for their participation. They all signed informed consent forms prior to participating in the experiment.

Stimuli. The stimuli consisted of 40 excerpts from commercially available recordings of the pieces listed in Table 1 and Appendix A. Stimuli ranged in duration from 12 s to 18 s. Excerpts were intended to be relatively texturally homogeneous for their full duration. Because we were interested in studying participants' responses to ecologically valid stimuli, the excerpts were not matched for loudness. Audio signals were sampled at 44.1 kHz. Additional excerpts from Robert Normandeau's *Clair de Terre* (2001; electronics) and Tristan Murail's *Désintégrations* (1996; orchestra and electronics) were used in practice trials to familiarize participants with the type of music they would be hearing and the experimental interface.

Procedure. Participants completed the experiment individually inside an Industrial Acoustics model 120-act3 double-walled sound isolation booth (IAC Acoustics, Bronx, NY). Musical excerpts were amplified with a Grace Design m904 monitor system and heard over circumaural Sennheiser HD280 Pro earphones (Sennheiser Electronic GmbH, Wedemark, Germany) at an average level of 60 dB SPL (A-weighted) for all participants.

Participants were told that the experimenters were researching semantic dimensions of sound mass perception, and given the following explanation of sound mass:

Sound mass exists when multiple sound events or sources are heard as a single meaningful unit.

Examples are encountered on a daily basis: a large crowd of people, a flock of birds, rustling leaves, traffic noise, shattering glass, etc. In each of these cases, the individual sound sources are no longer heard as individuals, but they contribute to the sound of the whole (i.e., the sound mass).

Music, especially contemporary music, frequently makes use of this phenomenon, creating textures in which many notes, sounds, instruments, voices, etc. are grouped into a mass. Musical sound masses may

be very different from one another in their sound quality, organization, and behaviour, but they always involve multiple sounds being grouped into a unit. In this study, we will refer to this grouping of sounds into a mass as *fusion*. There may be degrees of fusion, as some sounds may be grouped more strongly than others. It is possible for some of the sounds that you hear at any given time to fuse into a mass while others retain their individual identities, as when a single voice stands out from a crowd.

Participants heard the excerpts described above and rated them along three batteries of scales in three blocks. Each excerpt was heard and rated in each block, such that each of the 40 excerpts was encountered three times. On each encounter, participants heard the excerpt at least once, and had the option to hear it a second time.

The first block featured terms that appear frequently in published definitions of sound mass (Density, Complexity, Homogeneity). The second block featured adjectival metaphors used to describe sound mass (Volatile, Atmospheric, Busy, Static, Formless, Impenetrable, Voluminous, Kaleidoscopic). The third block featured nominal metaphors used to describe sound mass (Gas, Liquid, Solid, Clouds, Wind, Water, Webs, Galaxies, Crystals, Machinery, Herds/Crowds/ Swarms). Additionally, participants rated Fusion, which was taken to be a proxy for sound mass, in each of the three blocks, in order to assess how consistent participants are in their ratings of sound mass across multiple listenings for the same stimuli.

Participants completed the experiment on a Mac Pro computer (Apple Computer, Inc., Cupertino, CA). The interface was created in PsiExp (Smith, 1995) and consisted of a series of sliders (one for Fusion at the top, followed by others for each category in the block), which participants used to provide one rating per category for each excerpt in each block. Next to each of the Block 2 and Block 3 sliders was a "Questionable Relevance" button that listeners could select if they felt the scale was inapplicable to their experience; nevertheless, all participants were required to provide a value for each scale for all excerpts in all blocks. Additionally, in Blocks 2 and 3, there was an optional "Other (please specify)" slider that participants could use to add a scale if they wished to indicate an association not listed in the battery. At the bottom of the screen were a "Play" button, used to listen to the excerpt, and a "Next" button that loaded the following excerpt. The order of the blocks, the order of the stimuli within each block, and the order of the

semantic scales within each block were all randomized for each participant.

In Block 1, the question was worded "Please rate the example on each of the following scales," with a brief definition provided for each: Density (compactness of sound components); Complexity (intricacy or interconnectedness of sound components); Homogeneity (degree of similarity between sound components). These definitions did not identify specific musical parameters (e.g., pitch, rhythm, timbre); rather, participants were left to decide which attributes contribute to impressions of density, complexity, and homogeneity. At the end of Block 1, participants were asked to briefly describe their rating strategy for each of these categories. In Block 2 (adjectival metaphors), the instruction was worded "Please rate the degree to which you perceive the example to be" with a range defined for each individual scale (for example, from "Not volatile at all" to "Very volatile"; from "Not formless at all" to "Completely formless"; etc.). Brief definitions were provided for each term. In Block 3 (nominal metaphors), the question was worded "Please rate the degree to which the example reminds you of" with a range for each individual scale from "Very much" to "Not at all." No definitions were provided because these terms (clouds, water, crystals, etc.) were considered to be basic English vocabulary.

RESULTS

The ratings for each semantic scale appeared to show significant statistical coherence between participants: this was confirmed with a Cronbach's alpha test ($M = .90$, $SD = .04$). As a first step in interpreting these semantic ratings, the first author prepared a qualitative description for each stimulus addressing its rhythmic, pitch, dynamic, timbral, and gestural characteristics. These descriptions were based primarily on listening to the recordings, although the author also had familiarity with many of the corresponding scores. The characteristics along each parameter were described in fairly general terms that enabled comparison between the highly varied excerpts: for example, with respect to pitch, the presence or absence of stable pitch, clear harmonic structure, and glissandi were noted, along with rough descriptions of the register and compass. The descriptions were then discussed with the last author, and a final version was collaboratively prepared: we consider them to represent the carefully studied accounts of two expert listeners after many hearings. We later used these descriptions to investigate participants' ratings on the semantic scales, looking for commonalities between the descriptions of the highest and

TABLE 3: Simplified Summary of Subjective Descriptions of Stimuli

Stimulus	Rhythm (activity)	Pitch (register)	Dynamics (level)	Timbre	Global Gesture
1	very low	wide/saturated	low	homogeneous	no
2	v.low	wide/sat	high	homo	no
3	low	med-low	med	homo	yes
4	med	med	high	homo	yes
5	low	med-high	low	homo	no
6	low	med-low	med	homo	yes
7	low	wide/sat	low	homo	no
8	v.low	med-low	very low	homo	no
9	med	med	low	homo	yes
10	v.low	low	med	homo	no
11	v.low	low	high	homo	no
12	med	low	low	homo	yes
13	low	low	low	homo	yes
14	low	med	very high	homo	yes
15	low	wide/sat	v.high	homo	yes
16	low	med	med	homo	yes
17	low	med	med	heterogeneous	yes
18	high	med	high	homo	no
19	low	med-high	high	hetero	no
20	v.high	wide/sat	v.high	hetero	no
21	v.high	wide/sat	med	homo	yes
22	med	med	low	homo	yes
23	v.high	med	high	homo	yes
24	high	wide/sat	high	homo	no
25	v.high	med	high	hetero	no
26	high	med	med	hetero	no
27	high	med	low	hetero	yes
28	v.high	med-low	high	homo	yes
29	high	med	low	homo	yes
30	med	wide/sat	high	homo	no
31	med	med-low	low	hetero	no
32	high	med	high	hetero	no
33	high	med-high	high	hetero	no
34	med	high	med	hetero	yes
35	low	wide/sat	high	homo	yes
36	low	med-high	med	homo	yes
37	low	med	med	homo	yes
38	med	med-high	v.high	hetero	yes
39	high	med-low	high	hetero	yes
40	v.high	med	med	hetero	yes

lowest rated excerpts along each scale. A simplified version of the descriptions is represented in Table 3, focusing on one aspect of each parameter: degree of rhythmic activity (from very low to very high); pitch register (from low to high, or wide/saturated); dynamic level (from very low to very high); timbral homogeneity or heterogeneity (corresponding to well-blended emergent timbres on the one hand, and distinct dissimilar sound sources on the other); and the presence or absence of coherent global gesture among the parts. For a more detailed account, see the original descriptions in Appendix B.

We address participant ratings in relation to our qualitative descriptions below. Overall, the musicians' and nonmusicians' results (average ratings across each category) were highly correlated for each of the 24 scales, $r(38): M = .80, SD = .10$; we therefore treat them as a single population in this analysis. Mean ratings and standard deviations for all semantic scales in each of the three blocks are shown in Appendix C.

Fusion. Mean ratings of sound mass Fusion were strongly correlated between blocks (Table 4), suggesting that sound mass perception is highly consistent across

TABLE 4: Correlation Coefficients and *p* values for Fusion Ratings in Blocks 1, 2, and 3

Fusion	Block 1	Block 2	Block 3
Block 1	—		
Block 2	.968 < .001	—	
Block 3	.980 < .001	.972 < .001	—

Note: degrees of freedom = 38

multiple listenings to the same musical excerpts. As per the descriptions in Appendix B, Fusion ratings appear to relate most consistently to low rhythmic differentiation (i.e., the absence of perceptible attacks or other demarcators of discrete rhythmic events) and timbral homogeneity. Low register also appears to be a contributing factor, as does low pitch salience.

Block 1: Density, complexity, homogeneity. Correlations were calculated between the Block 1 scales, including Fusion, in order to determine if the emphases of published definitions of sound mass cohere with our participants' perceptions. Definitions of sound mass frequently invoke the concepts of density, complexity, and homogeneity, and we had initially assumed that Fusion would correlate strongly with all three. The results from Block 1 confirm that mean ratings for Homogeneity correlate robustly with Fusion, $r(38) = .865$, $p < .001$. Density also correlates positively but accounts for much less of the variance, $r(38) = .491$, $p < .001$. Complexity shows a strong *negative* correlation with Fusion, $r(38) = -.828$, $p < .001$, and also with Homogeneity, $r(38) = -.765$, $p < .001$. We interpret this as evidence of what Thoresen and Hedman (2015) describes as “paradoxical complexity,” in which a perceptually simple overall character emerges from a complex web of single parts (pp. 343–345; 457). Listeners are only able to make sense of relations between sound components up to a certain point, beyond which increasing the number or intricacy of relations between the components no longer results in increasing perceived complexity, but rather a simplifying assimilation of components into a global gestalt, at which point it begins to take on the character of a sound mass. The other pairings—Density-Complexity and Density-Homogeneity—did not correlate significantly.

Immediately after completing Block 1, participants were prompted to verbally describe their methods for rating Density, Complexity, and Homogeneity, to assess which sonic or musical parameters people associated with the three concepts. Some of the responses essentially reproduced the wording we provided, with

participants using the words “compactness” or “compact” in reference to Density, “intricacy” and “interconnectedness” in relation to complexity, and “similar” or “similarity” in relation to Homogeneity, while other choices of words were revealing of how participants conceptualized these terms.

Participants' descriptions of Density were heavily metaphorical. While some participants ($n=8$) described Density in terms of quantitative formulations (e.g., “how many layers,” “how many sounds came in at the same time,” “amount of overlap between the sounds”), and some made specific reference to musical or sonic properties such as loudness or volume ($n = 6$), silence ($n = 2$), speed ($n = 2$) and range ($n = 1$), many of the responses ($n = 16$) employed metaphorical language. Several of these ($n = 5$) were spatiotemporal in character (e.g., “if I felt that there was no room for any other instrument,” “how close the sounds were together”): it was sometimes ambiguous whether these spatiotemporal descriptions denoted temporal relations, spectral relations, or both. Several others ($n = 4$) employed material metaphors (e.g., “solid, like a wall of sound,” “if I felt I could cut the sound like a knife”). A number of other metaphors appeared, including weight/heaviness/lightness ($n = 6$), opacity ($n = 2$), fullness, strength, impact, fusion, busyness, and airiness ($n = 1$ each). Such varied descriptions do not provide a conclusive basis for understanding how Density is interpreted across subjects, but they suggest that it is a polysemic concept that may be mapped onto a wide variety of other domains, including a variety of musical and/or sonic properties.

Descriptions of rating strategies for Complexity were also highly varied, but somewhat more consistent: compositional relations between sounds emerged as a common theme. Several participants ($n = 8$) emphasized the sheer number of sounds/voices/parts/layers. Many participants ($n=10$) discussed how well the sounds interacted (e.g., “how well the sounds worked together as a single unit,” “how well they connected”) and/or employed related descriptive adjectives (e.g., “intricate,” “detailed,” “elaborate”) ($n = 8$). Several participants mentioned patterns ($n = 4$) or change ($n = 3$). Several participants related Complexity to specific musical parameters, including rhythm ($n = 4$), pitch (“harmony,” “range of tone,” “registers”) ($n = 3$), and timbre or color ($n = 2$). Several participants ($n = 4$) related Complexity to challenges to perceptual parsing (“how difficult it was to identify individual sounds,” “predictability of relation,” etc.). Several participants used the adjectival metaphors from our semantic scales to describe Complexity, including busy ($n = 5$), static, and volatile ($n = 1$ each).

Of the three scales, Homogeneity was identified by the most participants as being clearly associated with a single sonic parameter: timbre. A large majority of participants ($n = 31$) mentioned timbre and/or related concepts such as similarity of sounds, sound sources, sound components, instruments, and voices as their basis for Homogeneity ratings. Several participants ($n = 6$) mentioned other parameters such as pitch, unison, rhythm, beats, forms, and patterns, and two used cross-modal metaphorical descriptions: “smoothness of sound” and “if it feels (or sounds) ‘liquid’ or ‘fluid.’”

Some aspects of participants’ subjective verbal accounts of their rating strategies for Density, Complexity, and Homogeneity appear to be reflected in their numerical ratings. High ratings for Density correspond with our qualitative assessments of perceived loudness, spectral saturation over a wide compass (either noise-based sounds or large pitch clusters), and the absence of rhythmic differentiation. In some cases, there may also be a referential “density of information” with source-bonded sounds, as in the bee sounds from Wishart’s *Vox 5* and the panoply of sound sources in Normandeu’s “micro-montage” from *Clair de Terre*. For Complexity, rhythmic differentiation and timbral segregation appear to be important factors. Lutosławski’s excerpts, which typically employ aleatoric and asynchronous repetition of musical material, were rated highly for this category. For Homogeneity, timbral consistency was an important factor, as was low tessitura. Rhythmic differentiation seems not to influence perceived homogeneity, provided that it is metrical and regular. Pitch structure (i.e., vertical intervallic content) similarly seems not to be a determining factor. The lowest-rated excerpts are timbrally heterogeneous and have multiple discernible simultaneous strata.

Block 2: Adjectival metaphors. In Block 2, participants rated the excerpts for metaphorical associations presented in adjectival form. The following definitions were provided: Volatile (violently unstable), Atmospheric (creating an ambiance or environment), Busy (full of motion), Static (globally unchanging), Formless (lacking a coherent structure), Impenetrable (opaque, impossible to hear through), Voluminous (occupying physical space), Kaleidoscopic (having vivid, continuously changing colors and/or shapes). In general, we were able to interpret participants’ ratings for the adjectival categories in Block 2 in terms of identifiable musical attributes, qualitatively summarized below.

- (1) “Volatile” was associated with absence of stable pitch, emphasis on noisy or unstable timbres,

kinetic and dynamic textures, and continuous and/or unpredictable change.

- (2) For “Atmospheric,” vocal pieces were rated highly, while electroacoustic and noise-based pieces were rated lowly. Stable pitch structure, continuous sound, and slow, regular rhythm emerged as important factors.
- (3) For “Busy,” density of rhythmic activity appeared to be the primary factor. Timbre was less of a concern, with both homogeneous and heterogeneous examples rated highly.
- (4) For “Static,” the absence of rhythmic differentiation and global trajectory were determining factors, as was timbral homogeneity.
- (5) For “Formless,” perceptible harmonic structure and metrical rhythm were important negative factors (i.e., excerpts with clear harmonic and metrical structures tended to be rated lowly).
- (6) “Impenetrable” was associated with loud dynamics and spectral saturation, especially with noise-based timbre or chromatic saturation over a wide range.
- (7) For “Voluminous,” lowly-rated excerpts were characterized by short sound events, high degrees of internal motion, and/or soft dynamics. There is fair variety among the attributes of excerpts rated highly on this category.
- (8) “Kaleidoscopic” tended to be associated with timbral heterogeneity and internal dynamism or process, as well as with mid-high registers. Several “Shepard tone”-like examples were rated highly (excerpts 28, 39, 40), perhaps suggesting an affinity between two cross-modal types of circular or cyclical motion.

Block 3: Nominal metaphors. In Block 3, participants rated the excerpts for metaphorical associations presented in nominal form (Gas, Liquid, Solid, Clouds, Wind, Water, Webs, Galaxies, Crystals, Machinery, Crowds/Herds/Swarms). Block 3 ratings were generally more difficult to relate to consistent musical features than Block 2 ratings, leading us to consider the results case by case. Sometimes there were clear relations of sonic similarity between semantic categories and particular excerpts, in which cases ratings were very high: for instance, the bees in *Vox 5* (excerpt 17) and the shouting people in *Trois Poèmes d’Henri Michaux* (excerpt 38) were both rated highly for Crowds/Herds/Swarms, and the electroacoustic excerpts—especially the loud, noisy *Mycenae Alpha* (excerpt 14)—were rated highly for Machinery. Different excerpts sometimes seemed to draw on different mappings to the same semantic

TABLE 5: Principal Component Analysis, Block 2 and Block 3 Categories

Semantic Scale	Principal Component				
	1 “Liquid-Crystals”	2 “Busy-Crowds”	3 “Formless-Machinery”	4 “Voluminous-Solid”	5 “Wind-Gas”
Volatile	.104	.619	.604	.219	-.357
Atmospheric	-.098	.015	-.924	.260	.024
Busy	.344	.754	.459	-.052	-.214
Static	-.512	-.508	.118	.257	.455
Formless	.030	.281	.798	.165	.169
Impenetrable	-.367	.035	.320	.790	.214
Voluminous	-.153	.172	-.114	.936	.014
Kaleidoscopic	.713	.503	.049	-.208	-.288
Gas	-.087	-.327	.086	.062	.819
Liquid	.907	.005	.095	-.208	.094
Solid	-.168	-.381	.120	.667	-.434
Clouds	.041	-.406	-.607	-.091	.573
Wind	-.010	.063	-.038	.003	.902
Water	.900	.008	.093	-.165	.065
Webs	.420	.367	.191	-.495	-.250
Galaxies	.443	-.536	-.316	.063	.389
Crystals	.878	-.100	-.059	-.084	-.092
Machinery	-.071	-.102	.719	.586	-.041
Herds/Crowds/Swarms	-.126	.926	.029	.020	.026

Note. Percent variance explained is indicated for each PC. Kaiser-Meyer-Olkin Measure of Sampling Adequacy: .665 ($df = 171, p > .001$) Rotation method: Varimax with Kaiser normalization. Rotation converged in 7 iterations. Components with loadings above .6 and below -.6 shown in bold.

domain. For example, the filtered noise glissandi in *Sud B* (excerpt 16), which was rated highest for Wind, create a “rushing” sound, while the low register of *Atmosphères* (2) (excerpt 11), which was rated second highest, is similar to the rumble caused by wind blowing in one’s ears, or in a microphone. Three examples—*Points de Fuites*, *Asterism* (2), and *Crystal Music* (excerpts 40, 26, 33)—were all rated much higher for Crystals than any other excerpts; all are characterized by short sounds in a mid-high register, with a rhythmically active but not “saturated” texture. In some cases, the ratings are easier to interpret in terms of presumed topical significance. For example, the highest rated example for Galaxies was *Mortuos Plango, Vivos Voco* (excerpt 36), which is similar in its sinusoid-based timbres to soundtracks from early science fiction movies.

Principal component analyses. To examine the results for underlying factors that may have guided the ratings across the relatively large number of semantic domains, principal component analyses were conducted on the Block 2 and Block 3 categories (Tables 5 and 6). The semantic clusters revealed by this PCA are intuitive groupings and also map consistently onto musical properties. The PCs are named after strong contributing factors that give a sense of the semantic cluster.

- (1) Important musical attributes in PC1 (“Liquid-Crystal”) included timbral heterogeneity and mid-high register. Most of the excerpts with high values for this PC were “granular,” composed of large quantities of short sound events; exceptions (*Hyperion*, *Mortuos Plango*) featured slow, continuous motion, reflecting different but intuitive connotations of “liquid” and “water.”
- (2) PC2 (“Busy-Crowd”) was characterized by the uncoordinated activity of many parts. Lutosławski’s pieces have high values along this PC, as do some strongly source-bonded excerpts (Smalley, 1993), in which the sources of the sounds are evident to the listener (as in *Vox 5*, *Trois Poèmes d’Henri Michaux*, *Clair de Terre*; excerpts 15, 38, 20) and mimetic excerpts (O’Callaghan, 2015), in which musical sound imitates, or is perceived as imitating, sources that are evident to the listener (as in *Polymorphia* (2), *Ligeti DC* (1); excerpts 30, 22).
- (3) In PC3 (“Formless-Machinery”), electroacoustic and noise-based excerpts have high values, while vocal excerpts have very low values. This PC was characterized by loud dynamics and the absence of perceptible pitch structure or metrical rhythm.

TABLE 6: Values for All Excerpts on the Five Principal Components

Stim #	Principal Component				
	1	2	3	4	5
1	-0.82	-0.62	-1.27	0.00	1.04
2	0.30	-0.75	-0.81	-0.56	1.24
3	-0.03	-0.79	-1.32	-0.83	0.99
4	-1.05	-1.39	-0.31	-1.02	-0.14
5	-0.42	0.09	-1.06	0.02	0.35
6	-1.05	-1.11	-1.59	-0.14	-0.13
7	-0.95	-0.20	-0.91	0.63	0.62
8	-0.32	0.95	-1.95	0.29	-1.25
9	-1.84	-0.19	-0.39	0.38	-0.38
10	0.37	1.50	-0.82	-0.76	0.08
11	0.36	2.14	-1.08	-0.91	-0.06
12	-1.69	-0.52	-1.18	-0.78	0.24
13	-1.12	0.27	0.19	-1.01	0.68
14	1.83	-0.30	-1.34	-1.04	0.67
15	1.48	0.46	-0.18	-0.83	0.99
16	0.30	2.94	0.12	0.44	0.30
17	-0.33	0.37	2.31	-1.73	0.52
18	1.36	-0.52	-0.05	-0.85	0.44
19	1.20	-1.27	0.11	-0.42	0.11
20	1.36	-1.50	0.80	1.07	1.68
21	0.42	-0.70	0.16	0.62	-1.34
22	0.04	0.89	1.11	-0.90	-0.73
23	0.43	-0.95	0.55	-0.71	-0.34
24	1.42	-0.16	-0.12	0.85	0.27
25	1.28	0.22	-0.08	0.02	0.01
26	1.04	0.11	-0.23	2.08	-0.53
27	0.92	-1.29	-0.13	-0.49	-3.44
28	-0.01	-0.61	1.29	0.18	1.07
29	-0.08	0.70	0.85	-0.20	-1.68
30	0.04	1.46	1.72	-0.10	1.00
31	-0.17	0.21	0.48	-0.70	-1.93
32	0.12	-0.58	1.07	-0.37	-1.16
33	0.34	-0.57	0.36	2.40	-0.36
34	-0.43	-0.20	0.99	0.33	-1.08
35	0.37	1.64	0.38	-0.48	0.41
36	-0.01	0.85	-1.26	1.41	-0.21
37	-2.91	0.41	0.66	0.24	0.00
38	-0.70	-1.25	1.64	-0.53	0.88
39	-0.87	-0.02	0.90	1.69	0.87
40	-0.18	0.26	0.39	2.70	0.32

- (4) PC4 (“Voluminous-Solid”) involved loud dynamics, spectral saturation, low register and broad compass. Large clusters and noise-based examples have high values along this PC.
- (5) PC5 (“Wind-Gas”) was characterized by glissandi, continuity of sound, timbral homogeneity, low register, and the absence of rhythmic differentiation.

Participant-added categories. Participants also had the option to add categories of their own for each excerpt in Block 2 and Block 3. A total of 132 categories

were added. Some of these added categories reflected literal sound source identification or comparison (e.g., “busy bees,” “string pizzicato,” “a plane flying above,” “religious chants”). A number of others described affects (“excitement,” “confusing,” “playful,” “impending doom”), cross-modal associations (“darkness,” “heavy”), and types of motion (“flight,” “drifting”). Some added categories named specific objects or events (“lasers,” “mist,” “stairs”), and some referenced very specific tropes from film and popular culture (“taking you to the promised land,” “Cinderella’s evil step-mother,” “Alice in wonderland’s confusion,” “falling down the rabbit hole”). Many of the added categories suggest the imagery of movies, especially science fiction, fantasy, horror, and fairy-tale movies, which are likely the only contexts in which many participants would have experienced sound mass music (or contemporary music in general). This may indicate the influence of cultural associations rather than (or in addition to) analogical or metaphorical reasoning, an interesting finding that should be explored in future research.

ACOUSTICAL ANALYSES

Having established the associations between sound mass music and semantic descriptions, we sought to find a quantitative basis for these associations in the information in the acoustic signal. First, we attempted to correlate the semantic ratings to measurements of four classical audio descriptors, taken from the Timbre Toolbox (Peeters, Giordano, Susini, Misdariis & McA-dams, 2011): spectral spread, spectral flux, spectral centroid, and noisiness. Spectral centroid is the weighted average of the spectrum, and roughly correlates to perceived brightness. Spectral spread further characterizes the spectral shape by measuring its standard deviation around the spectral centroid. Spectral flux is a measure of the decorrelation between spectra in neighboring time frames; it characterizes rapid changes in spectral envelope and allows for the detection of transient events in sounds such as note onsets (Bello et al, 2005). Noisiness is a measure of non-harmonic energy and aims to quantify whether a sound is more or less tonal. It is computed by first modeling a sound as a harmonic signal (Serra, 1997) and then quantifying the energy unexplained by this model (for more information, see Peeters et al., 2011). As these are all time-varying descriptors, time-averaged values were used to perform the statistical analysis. With these figures, we computed a stepwise multilinear regression on each semantic scale. On average, 16% ($SD = 13\%$) of the variance was explained by the audio descriptors (see Figure 1). For four of the semantic scales, no significant correlation was found.

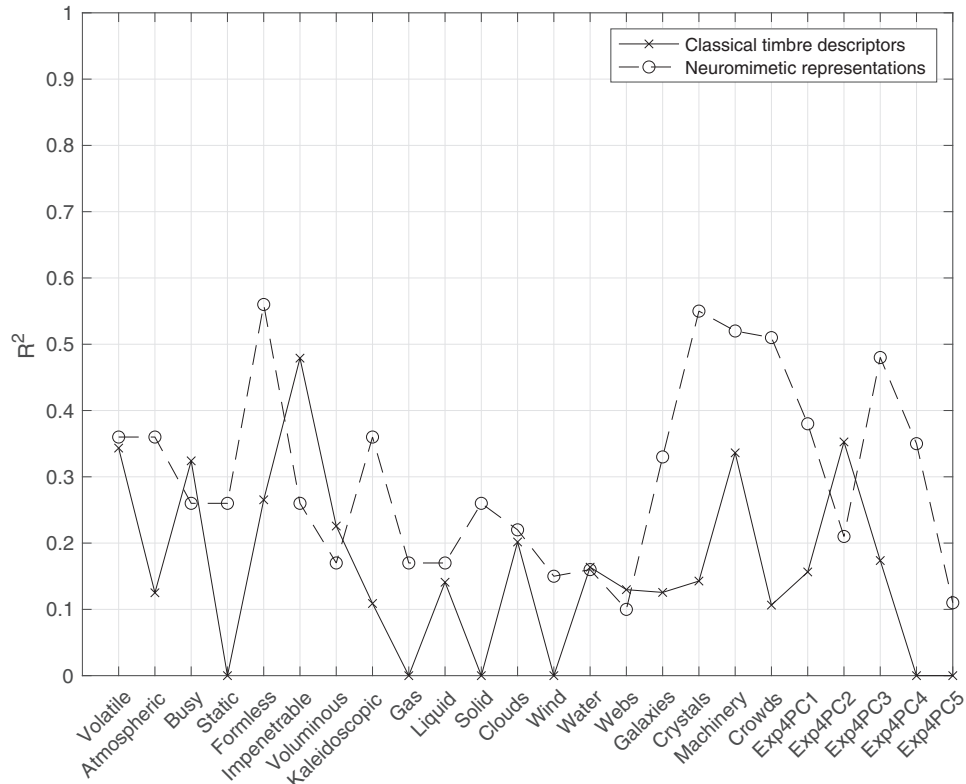


FIGURE 1. Explained variance (R^2) for each semantic scale with the stepwise multiple linear regression (in solid blue) and with the distance metric learning on neuromimetic representations (in dashed red).

Among the other semantic scales, we found no clear pattern of correlations associating any of the timbral features to a interpretatively coherent set of semantic scales. This leads us to conclude that no single descriptor or combination of descriptors from this group could efficiently explain the results. Given the dynamic nature of the stimuli, it was suggested that signal level might be a possible candidate for correlation. Level was calculated as the root mean square level (RMS) of the excerpt, normalized to the highest measured RMS value and expressed in decibels; i.e., the excerpt with the highest level was normalized to 0 dB. Expressed in this way, the stimuli had a dynamic range of -36.67 dB, with an average level of -16.36 dB and a standard deviation of 9.15 dB. Level also correlated poorly with the semantic ratings (largest $r^2 = .06$). These first analyses suggested that if an acoustic substrate of semantic rating can be found, we would need more sophisticated representations than classical audio descriptors to find it. We hypothesize that this might be due to the simplicity of the audio descriptors: noisiness, for instance as defined in the Timbre toolbox (Peeters et al., 2011), is calculated

in relation to an estimated fundamental pitch, but many of our excerpts are polyphonic, noise-based, or too spectrally complex for fundamental pitch to be relevant.

In order to go further, we used a second mathematical approach based on neuromimetic representations. These representations mimic sound processing in the cochlea and the primary auditory cortices, as modeled by so-called spectrotemporal receptive fields (STRFs) (Shamma, 2001). This model represents the spectrotemporal modulations embedded in a sound which have been shown to be crucial for the perception of speech (Elliot & Theunissen, 2009), music (Thoret, Depalle & McAdams, 2016), and environmental sound textures (Santoro et al., 2014). These kinds of representations, however, have a very large number of dimensions, and it is a challenge to determine which information is used by the auditory system in the perception of sound. Our goal here was to evaluate whether they embed enough information to predict semantic human ratings. As will be discussed below, the optimization of distances that reproduce human dissimilarity ratings between sounds from neuromimetic representations moves toward this

TABLE 7. Variance Explained by the Optimized Gaussian Kernels for Each Semantic Scale

Semantic Scale	Explained variance (r_p^2)
Volatile	.36
Atmospheric	.36
Busy	.26
Static	.26
Formless	.56
Impenetrable	.26
Voluminous	.17
Kaleidoscopic	.36
Gas	.17
Liquid	.17
Solid	.26
Clouds	.22
Wind	.15
Water	.16
Webs	.10
Galaxies	.33
Crystals	.55
Machinery	.52
Crowds	.51
PC1	.38
PC2	.21
PC3	.48
PC4	.35
PC5	.11
Average	.30 (SD = .13)

goal (Patil, Pressnitzer, Shamma, & Elhilali, 2012; Thoret, Caramiaux, Depalle, & McAdams, 2018).

NEUROMIMETIC REPRESENTATIONS OF SOUNDS

In order to model sounds, the most classical approach used in the literature is to consider their spectra, or the evolution of their spectra over time with time-frequency representations such as the spectrogram. These have been widely used as they model fairly well how the acoustic information could be processed at the first levels of the auditory system (i.e., in the outer and inner ears). Nevertheless, recent studies have pointed to more elaborated acoustics representations mimicking the processing of sounds achieved at higher levels of the auditory system (i.e., in the primary auditory cortex). These representations more accurately model the timbre of sound sources and in particular musical instrument sounds (Patil et al., 2012). These models consist in doing a multiresolution analysis of a time-frequency representation of a sound. Hence, they highlight the spectrotemporal modulations embedded in sounds. Here we used the neuromimetic model of spectrotemporal modulations proposed by Chi, Ru and Shamma (2005), which models sounds with a 4-dimensional tensor representing time, frequency, spectral modulations

(the *scales* in cycles/octave), and temporal modulations (the *rates* in Hz) of a given sound. More technically, initial processing in the cochlea is represented by a bank of asymmetric constant-Q filters; the processing of the inner hair cells and of the midbrain is simulated by spectral and temporal shaping of the filtered signal. Lastly, the central stage is modeled with a modulation filter bank centered on a grid of spectral and temporal modulations. We chose here to use 128 frequency channels for the cochlear analysis and the following rate and scale centers: rates: [-128, -64, -32, -16, -8, -4, -2, -1, -.5, .5, 1, 2, 4, 8, 16, 32, 64, 128] (Hz); scales: [0.25, 0.50, 1.0, 2.00, 4.00, 8.00] (cycles/octave). Positive and negative rates correspond respectively to rising and falling frequency patterns in sound spectrograms. This results in a 4D representation whose temporal dimension is then averaged to obtain a 3D tensor of 128 Frequency channels x 18 Rates x 6 Scales. More details on the computations of this representation are provided in Patil et al. (2012).

MIMICKING HUMAN DISSIMILARITY WITH DISTANCE METRIC LEARNING

In order to assess the relevance of these neuromimetic representations, we used a computational data-driven approach that optimizes a weighted distance (i.e., a Gaussian kernel), to mimic a given distance between semantic ratings. This approach, with an additional dimension-reduction, was initially proposed by Patil et al. (2012). Our recent improvement optimizes full (i.e., non-reduced representations; Thoret et al., 2018), allowing for direct observation of the metrics. Semantic ratings were first transformed into dissimilarities for each semantic scale: for each scale and for each pair of musical excerpts, the distance corresponding to the absolute value of the difference between the two ratings was computed. We then used a gradient descent to fit the weights of a gaussian kernel such that the distance between two neuromimetic representations would correspond to the distance between these two sounds derived from participants' semantic ratings. Finally, for each semantic scale we obtained a Pearson correlation coefficient representing goodness of fit and a metric capturing the important information emphasized in the neuromimetic representations in order to match the perceptual distances.

RESULTS

Table 7 summarizes the results of the optimization processes. On average across all the semantic scales, the gaussian kernels fitted on the neuromimetic representations explain 30% ($SD = 13\%$) of the variance in the

semantic ratings, which is higher than the results obtained with the audio descriptor approach. Although for some scales this is very low, it is notable that this model explains around 50% of the variance for several semantic scales, such as Formless, Galaxies, and Herds/Crowds/Swarms. We can deduce from these analyses that a potential acoustic substrate to semantic associations can be articulated more precisely in the spectrotemporal modulations than in the scalar audio descriptors. Nevertheless, the spectrotemporal modulations are not able to accurately fit the human ratings for all the semantic scales. There might be several reasons for this. For one thing, the representation used here considers a version of the STRFs averaged over time, but it is possible that the temporal dimension of sounds is a critical aspect of the semantic ratings. For another, although spectrotemporal modulations of sounds have proved their efficiency in correlating with basic perceptual tasks such as timbre dissimilarity ratings among musical instrument sounds, the task here is much more complex, and the model may be too simple to replicate the complex cognitive association task. Nevertheless, around 50% of the variance is explained for five scales, showing that STRFs can embed some relevant information used by humans in semantic judgments of auditory perceptions.

Discussion

When asked to rate excerpts from contemporary music along 23 selected semantic scales, listeners produced statistically coherent responses. Their ratings could often be linked to qualitative properties of the music (for example, Kaleidoscopic excerpts tended to be timbrally heterogeneous; Busy excerpts tended to feature uncoordinated activity of many parts). However, in some cases the interpretation was more difficult than in others: for example, the excerpts rated highly for Water had different and diverging properties that might have corresponded to very different associations with water, such as the sound of rain on a roof, the eternal descent of a waterfall, and the placid surface of a lake. When asked to describe their rating strategy for the Block 1 categories (Density, Complexity, Homogeneity, Fusion), participants were able to articulate specific qualities of the music and/or sound that they associated with each, and these responses were intersubjectively coherent enough to suggest a rough global picture (as described above). Following factor reduction in a principal component analysis, five principal components emerged with semantic clusters of scales: once again, these corresponded to properties

of the music that could be identified through qualitative analysis.

A precise account of the acoustic properties to which these semantic ratings correspond remains somewhat elusive. This is due partly to the complex nature of the cognitive task, which likely employs top-down schematic processes that cannot easily be deduced from an objective assessment of acoustic features (Siedenburg, Jones-Mollerup, & McAdams, 2016), and partly to the complex and diverse nature of the stimuli, which, as a trade-off for ecological validity, do not control systematically for variables. Perhaps it is unsurprising that analysis with classical acoustic descriptors in the Timbre Toolbox proved unsatisfactory, given that those tools were designed for simpler stimuli such as single musical notes. More sophisticated neuromimetic representations using spectrotemporal modulations produced much more encouraging results, accounting for about a third of the global variance for all categories, and over half of the variance for some of them.

Interestingly, of the categories that are best modeled using STRFs, some, such as Crowds and Machinery, invoke relations based on acoustic similarity. Others, such as Formless and Kaleidoscopic, invoke more abstract affinities based on cross-modal or other kinds of cross-domain relations, as these semantic domains do not specifically involve sound images. This suggests that musical meaning may employ a variety of types of coherent mappings familiar from the cognitive science of metaphor and analogy, including shared attributes, shared relations, and polysemy. Similar implications arise from the language used by participants to describe their semantic rating strategies and from the categories they added voluntarily. These combined qualitative and quantitative observations strongly suggest that listeners can and do experience semantic associations with sound mass music (at least in this experimental context), and that they found the selected set of semantic categories from composers' and theorists' discourse to be meaningful in relation to these musical excerpts.

Our study thus joins the chorus of recent research alluded to in the Introduction, arguing in favor of semantic interpretation as a pervasive and important aspect of musical experience in spite of the problem of plurality. The fact that many of our participants voluntarily added categories beyond those provided in our batteries of semantic scales indicates that semantic associations arise not only from a forced rating task, but also spontaneously through free interpretation. This parallels Margulis's (2017) finding in a study on narrative experiences of orchestral music that "participants *can* imagine narratives quite easily, even for music that

features less contrast . . . in the unrestrained form of free responses” (p. 242). That both Margulis’s participants and ours frequently invoked imagery from film and television—sometimes with very specific references—may suggest the presence of topical significance akin to conventionalized metaphors. But that human semantic ratings on the scales we provided could be partially reconstructed by a computer algorithm suggests a deterministic role of objective properties of the sound signal as well, and since 29 out of our 38 participants indicated no familiarity with sound mass music, it is unlikely that conventional codes account for *all* of the semantic dimensions observed in our study. It seems more likely that both top-down processes of culturally conditioned interpretations and bottom-up processes of novel mappings from musical attributes to extramusical domains have roles to play in emergent musical meaning, even in relatively unfamiliar styles of contemporary music such as sound mass. Although this type of music is very different from the commercial production music that was the subject of Huovinen and Kaila’s (2015) study of musical *topoi*, similar conclusions may be reached: some musical categories “hinge on rough and generic attributions, while others might be contingent upon specific, code-like musical features, and yet others . . . might emerge in highly complex ways from the simultaneous cultural interplay of various types of intuitive understandings” (p. 237).

Simply put, the fact that semantic interpretations of music may be plural does not make them arbitrary, unimportant, or “merely” subjective. Although the complexity of the many-to-many mappings involved in musical semantic judgments may seem daunting, our observations here suggest they may be at least partially explained through a combination of musical-acoustical analysis, perceptual study, and cultural interpretation. Our contribution is novel in its specific focus on contemporary music employing sound mass techniques, its combination of quantitative (*qua* numerical ratings on provided categories) and qualitative (*qua* voluntarily

added categories and self-reported ratings strategies) participant data, and its use of neuromimetic representations to computationally model the acoustic substrate of the semantic processing of music. While much work remains to be done in order to fully explicate the cognitive processes underlying semantic interpretations of music, we are encouraged by the observed degree of consistency between subjects in their reported semantic associations, and by the fact that human semantic ratings can be at least partially reconstructed by spectrotemporal modulations. We hope that future research will produce a more detailed account of these enormously rich and complicated phenomena, eventually producing a clearer picture of how music—including unfamiliar contemporary music—may become meaningful.

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Appendix A:

DOCUMENTATION OF STIMULI

The scores and recordings are listed in the Reference section.

Stimulus Number	Stimulus Name	Composer	Title	Location in Score	Time in Recording
1	Atmosphères (1)	György Ligeti	Atmosphères	m. 1	0:00
2	Threnody	Krzysztof Penderecki	Threnody to the Victims of Hiroshima	R. 70	9:08
3	Volumina	György Ligeti	Volumina	R. 1	0:15
4	Musique Funèbre	Witold Lutosławski	Musique funèbre	R. 240	9:05
5	Mi-Parti	Witold Lutosławski	Mi-parti	R. 40	10:04
6	Partiels	Gérard Grisey	Partiels	m. 1	0:05
7	Six Miniatures	Philippe Hurel	Six Miniatures en Trompe-l'œil	vi. m. 32	vi. 1:58
8	Du Cristal	Kaija Saariaho	Du cristal	R. H	3:02
9	Stimmung	Karlheinz Stockhausen	Stimmung	R. 12	mvt. 12, 0:12
10	Polymorphia (1)	Krzysztof Penderecki	Polymorphia	R. 8	1:35
11	Atmosphères (2)	György Ligeti	Atmosphères	m. 40	3:45
12	Gorecki Symphony No. 3	Henryk Górecki	Symphony No. 3	m. 26	1:12
13	Requiem	György Ligeti	Requiem	m. 3	0:12
14	Mycenae Alpha	Iannis Xenakis	Mycenae Alpha	beginning	0:00
15	Asterism (1)	Toru Takemitsu	Asterism	m. 88	6:50
16	Sud	Jean-Claude Risset	Sud	n/a	1:55
17	Vox	Trevor Wishart	Vox	n/a	2:18
18	Pacific	Barry Truax	Pacific	n/a	IV. 9:20
19	Tracés d'Ombres	Franck Bedrossian	Tracés d'Ombres	II. m. 5	3:20
20	Clair de Terre	Robert Normandeau	Clair de Terre	n/a	13:00:15
21	Pithoprakta	Iannis Xenakis	Pithoprakta	m. 49	2:14
22	Ligeti Double Concerto (1)	György Ligeti	Double Concerto for Flute, Oboe and Orchestra	m. 32	II: 1:15
23	Lutosławski Symohony No. 2	Witold Lutosławski	Symphony No. 2	R. 1	0:20
24	Riverrun	Barry Truax	Riverrun	n/a	2:15
25	Wings of Nike	Barry Truax	The Wings of Nike	n/a	II: 0:30
26	Crystal Music	Stéphane Roy	Crystal Music	n/a	8:55
27	Mimetismo	Stéphane Roy	Mimetismo	n/a	2:20
28	Lutosławski Double Concerto	Witold Lutosławski	Double Concerto for Oboe, Harp and Chamber Orchestra	m. 1	0:00
29	Ligeti Double Concerto (2)	György Ligeti	Double Concerto for Flute, Oboe and Orchestra	II: m. 56	II: 2:04
30	Polymorphia (2)	Krzysztof Penderecki	Polymorphia	R. 17	2:50
31	Ligeti Double Concerto (3)	György Ligeti	Double Concerto for Flute, Oboe and Orchestra	II: m. 1	II: 0:00
32	Jeux Vénitiens	Witold Lutosławski	Jeux vénitiens	R. A	0:01
33	Asterism (2)	Toru Takemitsu	Asterism	R. F	10:05
34	Ligeti Double Concerto (4)	György Ligeti	Double Concerto for Flute, Oboe and Orchestra	II: m. 121	4:30
35	Metastaseis	Iannis Xenakis	Metastaseis	m. 317	8:00
36	Mortuos Plango	Jonathan Harvey	Mortuos Plango, Vivos Voco	–	2:44
37	Jaanihaulud	Veljo Tormis	Jaanihaulud	m. 104	4:22
38	Trois Poèmes d'Henri Michaux	Witold Lutosławski	Trois Poèmes d'Henri Michaux	II: R. 48	II: 2:45
39	Hyperion	Georg F. Haas	Hyperion	R. L	25:08:00
40	Points de Fuites	Francis Dhomont	Points de Fuite	n/a	2:18

Appendix B:

SUBJECTIVE MUSICAL DESCRIPTIONS OF STIMULI

1. Atmosphères (1)

Rhythm: Little if any perceptible rhythm; some minor micro-fluctuation.

Pitch: Broad compass over wide range, densely and evenly distributed, sustained chromatic cluster.

Dynamics: Medium-soft, sustained dynamics.

Timbre: Consistent, well-blended orchestral tutti; exclusively pitched sounds.

Gesture: No sense of gesture except sustain.

2. Threnody

Rhythm: Little if any perceptible rhythm; some sense of irregular, uncoordinated fluctuation.

Pitch: Broad compass over wide range, densely and evenly distributed, sustained microtonal cluster.

Dynamics: Loud, sustained dynamics.

Timbre: Consistent, homogeneous string timbre; pitched sounds with some noise content.

Gesture: No sense of global gesture; some very slight sense of local gestures in fluctuation (e.g. bow changes).

3. Volumina

Rhythm: Low activity, no perceptible periodicity; two rhythmic events (cluster expansion).

Pitch: Broad compass over mid-low range, expanding into higher register

Dynamics: Medium-loud, getting louder with the addition of notes as the register expands upwards.

Timbre: Consistent and uniform organ timbre.

Gesture: Predominantly sustained, two discrete upward gestures.

4. Musique Funèbre

Rhythm: Regular, coordinated, periodic rhythm; progressive rallentando.

Pitch: Discrete pitches, mid-range tessitura, fairly narrow compass progressively diminishing, complex chromatic harmony contracting into a dense, narrow cluster.

Dynamics: Loud, sustained dynamics.

Timbre: Consistent and uniform string timbre.

Gesture: Clear, coherent, goal-directed gesture (contraction + rallentando to sustained cluster).

5. Mi-Parti

Rhythm: Low activity; some perceptible rhythm as voices breathe and re-enter.

Pitch: Discrete pitches, medium-high tessitura, fairly wide compass; sustained complex chromatic harmony.

Dynamics: Medium-soft, sustained dynamics.

Timbre: Wind instruments; exclusively pitched sounds; heterogeneous but well-blended, consistent, emergent timbre.

Gesture: No sense of gesture except sustain.

6. Partiels

Rhythm: Low activity; staggered soft entries result in minimal perceptible rhythmic activity.

Pitch: Discrete pitches, low-mid range, fairly wide compass; sustained harmonic spectrum.

Dynamics: Medium-loud low register followed by soft harmonic "shadow."

Timbre: Heterogeneous instruments but well-blended, evolving, emergent timbre.

Gesture: Upward migration of tessitura in a coherent global gesture, unified by harmonic spectrum.

7. Six Miniatures

Rhythm: Low activity; staggered entries resulting in some perceptible rhythm but no periodicity.

Pitch: Discrete, relatively stable pitches; wide range and compass; sustained inharmonic spectrum.

Dynamics: Medium-soft, sustained dynamics.

Timbre: Heterogeneous instruments; evolving, emergent timbre.

Gesture: No sense of gesture except timbral evolution.

(continued)

(continued)

8. Du Cristal*Rhythm:* Almost no perceptible rhythmic activity.*Pitch:* Discrete, sparsely distributed, stable pitches; medium-low range; fairly wide compass; inharmonic spectrum.*Dynamics:* Very soft, sustained dynamics.*Timbre:* Sustained, predominantly string timbre.*Gesture:* No sense of gesture. Static, sustained texture.**9. Stimmung***Rhythm:* Some rhythmic events created by entries. Superimposed periodic patterns created by vowel modulation.*Pitch:* Stable, sustained pitches, middle register (vocal), harmonic spectrum.*Dynamics:* Sustained, moderately soft dynamics.*Timbre:* Vocal, continuously modulating with vowel changes.*Gesture:* Mild sense of gesture created by oscillating timbral modulation and thickening harmony.**10. Polymorphia (1)***Rhythm:* Little if any rhythmic differentiation.*Pitch:* Very low register; dense, sustained pitches and glissandi; little or no perceptual resolution of discrete pitches.*Dynamics:* Sustained, moderately loud dynamics.*Timbre:* Homogeneous string timbre, but perceptually indistinct in this dense texture and very low register.*Gesture:* Little or no sense of gesture.**11. Atmosphères (2)***Rhythm:* Some sense of irregular internal dynamism but no clearly articulated rhythm.*Pitch:* Very low register, narrow compass, chromatically saturated.*Dynamics:* Sustained, medium-loud dynamics.*Timbre:* Homogeneous string timbre, but perceptually indistinct in this dense texture and very low register.*Gesture:* Little or no sense of gesture.**12. Gorécki Symphony No. 3***Rhythm:* Clear, metrical, moderately slow, periodic rhythm.*Pitch:* Very low register, narrow compass, diatonic structure.*Dynamics:* Sustained, medium-soft dynamics.*Timbre:* Homogeneous low string timbre.*Gesture:* Sense of gesture created by melodic counterpoint; no strong sense of global direction.**13. Requiem***Rhythm:* Rhythmic events created by syllables and introduction of new notes; no clear sense of metre or synchronous coordination between voices.*Pitch:* Low register, narrow compass, chromatic structure.*Dynamics:* Sustained, medium-soft dynamics.*Timbre:* Predominantly vocal timbre, bottom of male vocal range.*Gesture:* Sense of gesture created by melodic counterpoint; global contour of slow divergence.**14. Mycenae Alpha***Rhythm:* Some internal dynamism but little if any clear rhythmic delineation.*Pitch:* Mid-register; fairly narrow compass; little or no pitch salience; perceptual saturation.*Dynamics:* Loud dynamics with some fluctuation.*Timbre:* Synthetic, noisy timbre.*Gesture:* Some sense of gesture created by shifting contour; no clear sense of global direction.

(continued)

(continued)

15. Asterism (1)

Rhythm: Some internal dynamism, but difficult to discern because of the near-saturation of noise. No discernible coordination or periodicity between parts.

Pitch: Noise-based spectral saturation, little if any perceptible pitch structure.

Dynamics: Sustained, loud dynamics.

Timbre: Emergent from heterogeneous instruments, but percussion dominates (especially very loud cymbal roll).

Gesture: Global crescendo.

16. Sud

Rhythm: Rhythmic events created by event onsets and dynamic crests; no clear sense of metre, periodicity, or coordination.

Pitch: Diffuse (filtered noise) and unstable (glissandi) sense of pitch; middle register, fairly narrow compass.

Dynamics: Sustained, medium dynamics.

Timbre: Consistent, noise-based timbre, weak sense of pitch created by filtering.

Gesture: Shepard tone-like arrangement of staggered, descending glissandi.

17. Vox

Rhythm: Rhythmic events created by modulation of voice and by shifting sound sources; no clear sense of metre or periodicity.

Pitch: Narrow, mid-register pitch band corresponding to the approximate frequency of bees buzzing; overlapping and superimposed pitches within this range; no clear sense of harmonic structure.

Dynamics: Medium dynamics, inverted arch contour resulting from shifting sound sources.

Timbre: Beginning with vocal imitation of bees buzzing, shifting to sample of actual bees buzzing, returning to vocal sounds.

Gesture: Transformation-return gesture created by deployment of sound sources.

18. Pacific

Rhythm: Rapid, quasi-percussive rhythmic rearticulations; some local periodicity but no clear sense of metrical coordination; irregular accent structure.

Pitch: Little or no perceptible pitch; mid-register noise-based sounds.

Dynamics: Fluctuating medium-loud dynamics.

Timbre: Noise-based, granular, fluctuating timbre.

Gesture: Stratification between rapid foreground and drone-like background

19. Tracés d'Ombres

Rhythm: Some sense of rhythm created by timbral and dynamic modulation; little if any articulation of event onsets; no sense of metre or periodicity.

Pitch: Weak sense of unstable pitch in predominantly inharmonic sounds produced by extended techniques; medium and high tessituras; some loose pitch centricity but with continuous fluctuation and jitter; no clear sense of harmony.

Dynamics: Fluctuating medium-loud dynamics.

Timbre: Stratification of several timbral layers distinguished by register as well as spectral complexity: a rich, inharmonic mid-register layer, and a very high, squeaky, scratchy layer.

Gesture: Undulation within each of the stratified layers; no sense of global directedness.

20. Clair de Terre

Rhythm: Very dense activity from a panoply of sound sources; clear, periodic pulse at the beginning of the excerpt, followed by a montage texture with much rhythmic activity but no clear synchronicity.

Pitch: Some pitch in the various sound sources but no clear pitch structure in the montage; broad and constantly changing tessitura and compass.

Dynamics: Fluctuating loud dynamics.

Timbre: Highly complex and continuously changing; the composite of the many, densely superimposed sound sources creates an impression of saturation.

Gesture: Frenetic bombardment.

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21. Pithoprakta

Rhythm: Very dense rhythmic activity; many clearly defined event onsets (pizzicati) densely superimposed; no sense of metre or synchronicity.

Pitch: Wide tessitura and compass, changing over the course of the excerpt (at times broad saturation, at times emphasizing the low register); pizzicato onsets most perceptually salient, but each note glisses following the onset; no clear harmony or pitch structure.

Dynamics: Covarying with tessitura; ranging from medium-soft to medium-loud.

Timbre: Homogenous string timbre, covarying somewhat with register.

Gesture: Globally shifting register creates downward-migrating gestural gestalt.

22. Ligeti Double Concerto (1)

Rhythm: Dense, rapid, tremolo-like rearticulations; local, superimposed, shifting periodicities; no clear sense of metrical synchronicity.

Pitch: Brief but stable pitches; narrow, middle-register compass; diatonic intervals (m3 + M2) emphasized initially, followed by chromatic filling in.

Dynamics: Soft dynamics; slight crescendo over the course of the excerpt.

Timbre: String timbres, gradually transforming to emphasize upper harmonics (SP).

Gesture: Gradual timbral shift and chromatic filling-in create a progressive intensification.

23. Lutosławski Symphony No. 2

Rhythm: Asynchronous, attack-dense, superimposed patterns between multiple instruments; some individual metrical organization but no synchronous coordination or common pulse.

Pitch: Fairly narrow compass, middle-register tessitura, chromatically saturated overall pitch structure but with continuously and indeterminately changing configurations as per the aleatoric texture.

Dynamics: Fluctuating, loud dynamics; slight decrescendo over the course of the excerpt.

Timbre: Fairly homogeneous brass timbre; some notes standing out as brasher.

Gesture: Slight decrease in compass / tessitura and loudness creates slight but progressive diminishing of intensity.

24. Riverrun

Rhythm: Very dense, granular texture; a very large number of very short, superimposed sound events; continuous activity but no sense of pulse, meter, or synchronous coordination.

Pitch: Distributed stochastically and microtonally across broad range.

Dynamics: Sustained medium-loud dynamics; imposed decrescendo at the end.

Timbre: Sine tones and frequency-modulated sine tones distributed stochastically via granular synthesis; possible to hear multiple strata if low and high registers are perceived as distinct layers; also possible to hear as an amalgamated whole.

Gesture: No clear sense of gesture, apart from continuous, frenetic activity.

25. Wings of Nike

Rhythm: Rapid, granulated rearticulation of short sound events; no clear sense of metrical synchrony.

Pitch: Stable pitches; prominent m7 in middle register; other lower sounds in background.

Dynamics: Sustained, medium-loud dynamics.

Timbre: Synthesized sounds; quasi-vocal quality in one stratum; indistinct rumble in another.

Gesture: No clear sense of gesture; continuous, dense rhythmic activity and sustained pitch.

26. Crystal Music

Rhythm: At least three distinct layers: (i) many short, very rapid micro-events similar to a “shatter” pattern, (ii) slow-moving notes, and (iii) a drone with no rhythmic differentiation.

Pitch: (i) has predominantly medium-high sounds with little pitch salience, (ii) consists of mid-register notes with strong pitch salience and diatonic intervals (parallel m3s), (iii) is a low rumble with little if any pitch salience.

Dynamics: Fluctuating medium-soft – medium-loud dynamics.

Timbre: Distinct timbres for each layer: (i) inharmonic / noisy; lack of clear pitch due to large number of very brief, superimposed events; (ii) harmonic synthetic timbre, “flutey” sound; (iii) indistinct, noisy. Other sounds include sine wave-like timbres in brief, granular textures.

Gesture: Pitch ascent in (ii) gives an overall ascending character; movement towards a brighter, synthetic timbre at the end gives a sense of intensification.

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27. Mimetismo

Rhythm: Very rhythmic texture; relatively sparse, short sound events with clearly defined attacks. Some periodicity in guitar tremolo, but at too rapid a pace to be perceived as metrical; some loose sense of meter emerges towards the end of the excerpt.

Pitch: Little sense of pitch in electronic sounds; strong sense of pitch in guitar sounds; low “pedal tone” with upward bending throughout excerpt, some mid-register chords emphasizing m3s in a chromatic ascending pattern in the latter part of the excerpt.

Dynamics: Soft for most of the excerpt, becoming louder towards the end.

Timbre: Inharmonic granular electronic sounds, juxtaposed with unprocessed acoustic guitar.

Gesture: Overall sense of ascent and intensification, primarily driven by the guitar layer.

28. Lutosławski Double Concerto

Rhythm: Very dense, uncoordinated activity; local periodicity in individual parts, but no common pulse or meter.

Pitch: Chromatic saturation in mid-low register; less dense motion in counterpointed voices in low and medium-high registers.

Dynamics: Sustained loud dynamics.

Timbre: Relatively homogeneous string timbre.

Gesture: Mini-Shepard-tone-like gesture in repeated rapid descent in mid-low register; gradual splitting off of contrapuntal voices creates increased stratification and consequently a diminishing sense of unity or coherence.

29. Ligeti Double Concerto (2)

Rhythm: Fairly dense rhythmic activity in fluctuating degrees throughout the excerpt; periodicity in local gestures whose phases change relative to one another somewhat irregularly, such that there is no overarching sense of meter but quasi-metrical moments emerge and then disappear.

Pitch: Chromatically saturated m3 in mid-register.

Dynamics: Fluctuating soft dynamics.

Timbre: Homogeneous flute-dominated timbre, fairly dull and diffuse at the bottom of the instrument’s range.

Gesture: Interweaving and overlapping of similar gestures; gradual thinning of texture over course of excerpt.

30. Polymorphia (2)

Rhythm: Very dense activity; some rhythmic pop-outs caused by rapid registral displacement but predominant sense of rhythmic saturation and therefore indiscriminability.

Pitch: Little or no clear sense of pitch, due to spectral saturation and pervasive glissandi.

Dynamics: Sustained medium-loud dynamics with micro-fluctuations as voices move transiently into different registers.

Timbre: Homogeneous string timbre, but creating a “vocal” illusion of a crowd of people through its organization.

Gesture: No clear sense of global gesture.

31. Ligeti Double Concerto (3)

Rhythm: Tremolo-type rapid rearticulation; some local periodicity but continuously changing, with no clear or sustained sense of pulse or meter.

Pitch: Mid-low register, narrow compass, only two pitches separated by m3 for most of the excerpt; small amount of chromatic expansion towards the end.

Dynamics: Medium-soft dynamics with some minor fluctuation.

Timbre: Somewhat heterogeneous woodwind timbre, shifting from clarinet-based to bassoon-based.

Gesture: Little sense of gesture; subtle trajectory of expansion and timbral intensification.

32. Jeux Vénitiens

Rhythm: Complex, active, and moderately dense polyrhythm; some local periodicity but no coordination, pulse, or meter between the parts.

Pitch: Fairly wide compass from mid-low to mid-high register; complex chromatic pitch content, which, combined with lack of synchronous coordination, inhibits the emergence of a discernible or stable harmonic structure.

Dynamics: Medium-loud dynamics, fluctuating with changes in other parameters.

Timbre: Very heterogeneous, woodwind-based timbre.

Gesture: Strong sense of superposition of multiple gestures, each with its own contour, trajectory, and rhythmic profile, but with no global sense of gestural coherence or coordination.

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33. Asterism (2)

Rhythm: Complex, active, fairly dense polyrhythm. Some local periodicity but no coordination, pulse, or meter between the parts.

Pitch: Fairly wide compass from medium to high register; complex chromatic pitch content, which, combined with lack of synchronous coordination, inhibits the emergence of discernible or stable harmonic structure.

Dynamics: Medium-loud dynamics, fluctuating with changes in other parameters.

Timbre: Very heterogeneous ensemble timbre, with prominent woodwinds and percussion.

Gesture: Strong sense of superposition of multiple gestures, each with its own contour, trajectory, and rhythmic profile, but with no global sense of gestural coherence or coordination.

34. Ligeti Double Concerto (4)

Rhythm: Highly varied over the course of the excerpt, with moments of dense activity alternating with moments of relatively long sustained events (pitch bends in addition to stable pitches). Strong sense of rhythmic coordination between the parts but no clear periodicity or meter.

Pitch: High register; fairly narrow compass varying over the course of the excerpt from about a tritone to near-unison with microtonal inflection.

Dynamics: Fairly steady, medium-loud dynamics; some fluctuation with changes in pitch and rhythm.

Timbre: Fairly heterogeneous ensemble timbre, with prominent woodwinds.

Gesture: Coordinated global gestural alternation between kinetic activity and relative repose.

35. Metastaseis

Rhythm: Little if any rhythmic differentiation due to continuous glissandi; some “events” created by local crests and troughs of pitch structure.

Pitch: Very wide initial compass ranging from very low to very high; no sense of stable pitch as all voices move in continuous glissandi; gradual process of contraction over the course of the excerpt with some irregular trajectories.

Dynamics: Varying smoothly over the course of the excerpt, ranging from medium-soft to loud.

Timbre: Homogeneous string timbre.

Gesture: Coherent, coordinated gesture of progressive registral contraction in “common fate” motion.

36. Mortuos Plango

Rhythm: Little rhythmic differentiation due to continuous glissandi; rhythmic events created by the introduction of new discrete pitches which then proceeds to glissando, and (less saliently) by the disappearance of other voices.

Pitch: Fairly wide compass from medium to high; continuously changing inharmonic pitch structure; greater and lesser degrees of instability in pitch due to continuously changing slope of glissandi.

Dynamics: Varying (mostly smoothly) over the course of the excerpt, ranging from soft to medium.

Timbre: Synthetic sine-tones, some emergent timbre from combinations of tones.

Gesture: Coherent, coordinated, two-phase gesture, first of contraction to a point of harmonic arrival (similar to a minor chord), followed by progressive ascent and divergence of sine tones.

37. Jaanilalud

Rhythm: Relatively low degree of rhythmic activity; unwavering rhythmic unison; clear 4/4 meter; steady tempo at a moderate pace.

Pitch: Parallel “planing” of diatonic chord (M9) under diatonic melody; moderately wide compass ranging from mid-low to mid-high register.

Dynamics: Fairly sustained medium dynamics.

Timbre: Fairly homogeneous vocal timbre (mixed-voice choir).

Gesture: Completely unified, globally coherent melodic gesture; prototypical “common fate” motion.

38. Trois Poèmes d’Henri Michaux

Rhythm: Rhythmic differentiation most salient in percussion and wind instruments, with clearly defined events and quasi-periodic timing; no clear rhythm in voices, which are coordinated neither with the percussion nor with one another.

Pitch: Fairly wide compass from medium to high range; little stable pitch content due to continuous glissandi.

Dynamics: Sustained loud dynamics with some internal fluctuation.

Timbre: Two timbral strata: continuous wash of vocal shouts / downward glissandi, and heterogeneous, sparse percussion-piccolo overlay.

Gesture: Clear stratification between voices and instruments; voices create a noisy, quasi-Shepard-tone effect; instruments punctuate with brief rhythmic gestures; little sense of coherence between the two layers, or of global gestural direction.

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39. Hyperion

Rhythm: Fairly high degree of rhythmic activity, increasing (accelerating) over the course of the excerpt; local periodicity and gestural coordination but little or no sense of overall pulse or meter.

Pitch: Discrete, stable pitches, gradually decreasing in duration over the course of the excerpt; wide compass with most pitches concentrated in the mid-low register; superimposed octatonic and chromatic scale patterns.

Dynamics: Medium-loud dynamics with some internal fluctuation; small crescendo over the course of the excerpt.

Timbre: Very heterogeneous instrumental ensemble, some instruments standing out more than others (especially the piano).

Gesture: Orchestrated accelerating Shepard tone.

40. Points de Fuites

Rhythm: Very dense rhythmic activity, many very brief (granular) events, clear coordination into overlapping descending gestures, no clear sense of pulse or meter.

Pitch: Quasi-whole-tone scale patterns in descending gestures, microtonally superimposed; pitch content concentrated in a fairly narrow mid-register compass, with non-pitched sound components extending to both high and low registers.

Dynamics: Fluctuating medium-soft – medium-loud dynamics.

Timbre: Synthetic, granulated timbre; mixture of inharmonic and noise-based sounds.

Gesture: Synthetically orchestrated, irregular Shepard tone.

Appendix C:

MEAN RATINGS AND STANDARD DEVIATIONS FOR ALL STIMULI

(a) Block 1:

Stim #	Fusion		Density		Complexity		Homogeneity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	0.75	0.24	0.72	0.28	0.37	0.30	0.74	0.23
2	0.76	0.20	0.77	0.24	0.49	0.30	0.69	0.25
3	0.71	0.23	0.84	0.18	0.36	0.30	0.77	0.21
4	0.54	0.29	0.58	0.26	0.56	0.29	0.70	0.23
5	0.73	0.21	0.69	0.30	0.44	0.29	0.71	0.26
6	0.60	0.30	0.59	0.29	0.37	0.26	0.56	0.28
7	0.64	0.27	0.67	0.25	0.48	0.26	0.63	0.25
8	0.77	0.23	0.44	0.34	0.29	0.28	0.78	0.24
9	0.40	0.30	0.43	0.29	0.52	0.28	0.56	0.28
10	0.81	0.20	0.69	0.30	0.32	0.27	0.78	0.26
11	0.82	0.25	0.64	0.32	0.22	0.26	0.83	0.26
12	0.72	0.26	0.65	0.30	0.29	0.22	0.84	0.17
13	0.70	0.28	0.71	0.27	0.37	0.24	0.75	0.28
14	0.81	0.23	0.77	0.25	0.44	0.29	0.77	0.27
15	0.72	0.27	0.80	0.26	0.56	0.30	0.66	0.31
16	0.79	0.23	0.63	0.28	0.38	0.27	0.76	0.25
17	0.59	0.32	0.71	0.26	0.55	0.30	0.74	0.30
18	0.41	0.30	0.59	0.27	0.64	0.23	0.59	0.26
19	0.38	0.28	0.60	0.25	0.67	0.22	0.37	0.28
20	0.17	0.20	0.74	0.29	0.83	0.26	0.16	0.23
21	0.34	0.31	0.46	0.31	0.62	0.26	0.61	0.30
22	0.59	0.32	0.50	0.32	0.53	0.31	0.76	0.23
23	0.35	0.29	0.55	0.26	0.69	0.24	0.50	0.31
24	0.51	0.37	0.62	0.29	0.63	0.30	0.67	0.31
25	0.53	0.32	0.69	0.25	0.60	0.27	0.70	0.27
26	0.39	0.28	0.43	0.29	0.61	0.25	0.37	0.26
27	0.20	0.20	0.18	0.13	0.50	0.28	0.29	0.23
28	0.42	0.32	0.69	0.25	0.79	0.18	0.46	0.31
29	0.44	0.30	0.39	0.24	0.56	0.32	0.64	0.32
30	0.56	0.29	0.70	0.26	0.50	0.30	0.47	0.32
31	0.44	0.30	0.38	0.30	0.50	0.30	0.67	0.28
32	0.20	0.21	0.46	0.30	0.73	0.25	0.36	0.29
33	0.19	0.24	0.45	0.28	0.71	0.23	0.27	0.26
34	0.33	0.27	0.43	0.27	0.66	0.25	0.54	0.30
35	0.78	0.22	0.73	0.24	0.40	0.28	0.74	0.25
36	0.81	0.24	0.51	0.32	0.36	0.28	0.75	0.24
37	0.64	0.35	0.56	0.28	0.41	0.34	0.73	0.30
38	0.34	0.31	0.66	0.23	0.57	0.27	0.39	0.29
39	0.51	0.26	0.64	0.27	0.66	0.23	0.44	0.31
40	0.35	0.27	0.52	0.24	0.68	0.24	0.48	0.31

(b) Block 2

Stim #	Fusion		Volatile		Atmospheric		Busy		Static		Formless		Impenetrable		Voluminous		Kaleidoscopic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	0.78	0.25	0.27	0.27	0.69	0.28	0.33	0.28	0.71	0.31	0.47	0.34	0.61	0.33	0.69	0.25	0.24	0.27
2	0.77	0.24	0.50	0.34	0.58	0.32	0.49	0.31	0.68	0.27	0.68	0.28	0.72	0.27	0.68	0.28	0.25	0.28
3	0.74	0.27	0.40	0.33	0.63	0.30	0.30	0.29	0.73	0.26	0.54	0.36	0.70	0.32	0.72	0.29	0.23	0.24
4	0.53	0.34	0.47	0.30	0.62	0.29	0.57	0.23	0.33	0.29	0.27	0.27	0.47	0.32	0.62	0.26	0.39	0.31
5	0.69	0.26	0.30	0.28	0.58	0.32	0.30	0.23	0.74	0.23	0.49	0.29	0.59	0.26	0.59	0.30	0.32	0.28
6	0.54	0.33	0.33	0.27	0.64	0.29	0.27	0.26	0.46	0.29	0.38	0.28	0.49	0.28	0.58	0.29	0.29	0.27
7	0.67	0.24	0.37	0.28	0.71	0.23	0.34	0.24	0.50	0.29	0.41	0.25	0.49	0.29	0.64	0.26	0.43	0.31
8	0.83	0.23	0.12	0.18	0.55	0.34	0.17	0.25	0.81	0.26	0.57	0.39	0.41	0.36	0.31	0.33	0.17	0.22
9	0.42	0.30	0.20	0.24	0.74	0.27	0.29	0.25	0.47	0.34	0.33	0.29	0.21	0.24	0.47	0.29	0.58	0.27
10	0.79	0.25	0.28	0.28	0.56	0.33	0.33	0.27	0.77	0.27	0.57	0.35	0.65	0.30	0.69	0.26	0.18	0.21
11	0.88	0.16	0.20	0.24	0.56	0.34	0.24	0.26	0.85	0.19	0.61	0.37	0.60	0.34	0.67	0.28	0.14	0.19
12	0.67	0.30	0.24	0.26	0.73	0.27	0.24	0.23	0.55	0.32	0.17	0.24	0.43	0.30	0.71	0.26	0.23	0.25
13	0.80	0.20	0.32	0.27	0.70	0.26	0.34	0.30	0.64	0.31	0.45	0.34	0.63	0.31	0.68	0.27	0.23	0.23
14	0.80	0.21	0.56	0.33	0.45	0.32	0.60	0.29	0.75	0.27	0.62	0.33	0.75	0.29	0.68	0.27	0.28	0.29
15	0.79	0.20	0.56	0.36	0.46	0.34	0.59	0.31	0.76	0.24	0.61	0.35	0.76	0.28	0.72	0.28	0.26	0.29
16	0.78	0.21	0.34	0.29	0.55	0.32	0.52	0.30	0.58	0.33	0.56	0.31	0.59	0.30	0.58	0.31	0.38	0.31
17	0.66	0.29	0.65	0.27	0.63	0.33	0.81	0.21	0.51	0.32	0.58	0.35	0.63	0.28	0.68	0.28	0.42	0.32
18	0.53	0.33	0.74	0.26	0.52	0.33	0.75	0.24	0.58	0.35	0.64	0.31	0.64	0.34	0.57	0.33	0.37	0.34
19	0.29	0.25	0.78	0.24	0.54	0.33	0.71	0.23	0.28	0.26	0.66	0.29	0.54	0.32	0.69	0.23	0.53	0.34
20	0.26	0.31	0.86	0.17	0.52	0.40	0.92	0.11	0.11	0.23	0.74	0.34	0.62	0.36	0.80	0.23	0.74	0.33
21	0.32	0.33	0.47	0.31	0.48	0.31	0.71	0.24	0.28	0.31	0.56	0.30	0.32	0.27	0.40	0.27	0.60	0.30
22	0.58	0.33	0.54	0.32	0.54	0.32	0.69	0.28	0.55	0.34	0.49	0.31	0.41	0.30	0.40	0.29	0.40	0.32
23	0.24	0.24	0.62	0.29	0.48	0.35	0.82	0.15	0.30	0.31	0.63	0.30	0.48	0.31	0.61	0.28	0.55	0.30
24	0.54	0.37	0.60	0.32	0.44	0.29	0.84	0.16	0.55	0.36	0.64	0.32	0.63	0.30	0.60	0.28	0.51	0.34
25	0.47	0.35	0.59	0.33	0.38	0.29	0.69	0.29	0.68	0.33	0.58	0.34	0.57	0.34	0.61	0.28	0.40	0.34
26	0.35	0.29	0.51	0.29	0.47	0.29	0.69	0.19	0.33	0.29	0.65	0.27	0.42	0.28	0.50	0.27	0.60	0.33
27	0.20	0.21	0.52	0.34	0.38	0.31	0.63	0.27	0.22	0.24	0.56	0.32	0.20	0.21	0.27	0.26	0.55	0.32
28	0.46	0.33	0.68	0.28	0.58	0.33	0.84	0.17	0.35	0.31	0.53	0.31	0.57	0.33	0.65	0.28	0.62	0.30
29	0.45	0.30	0.42	0.31	0.49	0.31	0.66	0.24	0.42	0.31	0.48	0.28	0.26	0.22	0.39	0.29	0.51	0.30
30	0.60	0.32	0.54	0.29	0.60	0.32	0.72	0.26	0.44	0.31	0.73	0.21	0.62	0.28	0.68	0.27	0.42	0.32
31	0.48	0.29	0.41	0.25	0.49	0.33	0.61	0.22	0.43	0.30	0.47	0.29	0.31	0.25	0.37	0.27	0.36	0.29
32	0.21	0.19	0.48	0.29	0.49	0.28	0.81	0.16	0.22	0.23	0.55	0.30	0.34	0.29	0.43	0.28	0.64	0.21
33	0.25	0.24	0.52	0.34	0.53	0.31	0.81	0.18	0.33	0.34	0.58	0.32	0.36	0.27	0.53	0.28	0.69	0.31
34	0.31	0.25	0.48	0.30	0.58	0.26	0.70	0.23	0.20	0.21	0.49	0.30	0.28	0.27	0.38	0.26	0.66	0.19
35	0.76	0.24	0.44	0.29	0.55	0.31	0.49	0.28	0.59	0.26	0.55	0.31	0.66	0.26	0.68	0.24	0.37	0.30
36	0.83	0.21	0.32	0.26	0.56	0.33	0.26	0.25	0.58	0.29	0.51	0.30	0.48	0.33	0.51	0.32	0.34	0.32
37	0.57	0.35	0.11	0.15	0.79	0.25	0.31	0.26	0.32	0.30	0.13	0.18	0.29	0.25	0.62	0.28	0.44	0.28
38	0.37	0.28	0.56	0.31	0.68	0.31	0.78	0.23	0.34	0.31	0.64	0.30	0.49	0.31	0.65	0.30	0.48	0.32
39	0.45	0.30	0.46	0.32	0.67	0.27	0.75	0.19	0.26	0.26	0.37	0.30	0.49	0.30	0.70	0.25	0.71	0.24
40	0.32	0.29	0.52	0.26	0.55	0.27	0.80	0.17	0.31	0.32	0.52	0.31	0.43	0.28	0.58	0.28	0.70	0.29

(c) Block 3

Stim #	Fusion		Gas		Liquid		Solid		Clouds		Wind		Water		Webs		Galaxies		Crystals		Machinery		Herds/ Crowds /Swarms	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	0.80	0.21	0.21	0.27	0.15	0.22	0.25	0.30	0.20	0.28	0.37	0.32	0.17	0.25	0.20	0.26	0.46	0.36	0.28	0.31	0.32	0.36	0.39	0.32
2	0.80	0.20	0.18	0.21	0.08	0.14	0.27	0.32	0.20	0.27	0.33	0.33	0.15	0.21	0.20	0.29	0.40	0.34	0.17	0.25	0.45	0.37	0.51	0.38
3	0.72	0.27	0.27	0.31	0.08	0.15	0.40	0.36	0.17	0.26	0.27	0.31	0.07	0.16	0.25	0.33	0.32	0.33	0.16	0.25	0.39	0.36	0.30	0.33
4	0.53	0.34	0.15	0.21	0.11	0.17	0.36	0.35	0.22	0.29	0.32	0.34	0.12	0.22	0.27	0.31	0.34	0.34	0.07	0.13	0.28	0.34	0.42	0.36
5	0.71	0.22	0.26	0.32	0.17	0.24	0.28	0.32	0.28	0.30	0.41	0.34	0.15	0.21	0.21	0.26	0.46	0.35	0.18	0.28	0.21	0.31	0.24	0.30
6	0.63	0.29	0.22	0.28	0.13	0.21	0.45	0.34	0.33	0.35	0.25	0.30	0.17	0.24	0.12	0.20	0.38	0.34	0.19	0.26	0.29	0.30	0.15	0.21
7	0.62	0.28	0.34	0.30	0.17	0.24	0.25	0.30	0.37	0.35	0.31	0.31	0.20	0.23	0.29	0.28	0.50	0.33	0.23	0.27	0.32	0.34	0.21	0.26
8	0.77	0.25	0.39	0.34	0.17	0.26	0.19	0.27	0.42	0.36	0.38	0.33	0.19	0.25	0.18	0.27	0.51	0.31	0.33	0.30	0.17	0.24	0.13	0.21
9	0.53	0.30	0.30	0.33	0.21	0.28	0.18	0.28	0.39	0.38	0.32	0.32	0.27	0.29	0.20	0.26	0.47	0.35	0.24	0.29	0.12	0.24	0.39	0.36
10	0.84	0.21	0.47	0.37	0.15	0.24	0.40	0.36	0.35	0.38	0.47	0.33	0.15	0.23	0.21	0.30	0.32	0.36	0.06	0.11	0.46	0.38	0.28	0.32
11	0.86	0.17	0.47	0.36	0.14	0.22	0.32	0.38	0.40	0.36	0.58	0.37	0.22	0.30	0.11	0.18	0.35	0.34	0.06	0.17	0.48	0.38	0.31	0.33
12	0.72	0.28	0.27	0.31	0.13	0.21	0.50	0.38	0.29	0.33	0.28	0.31	0.11	0.18	0.18	0.23	0.42	0.36	0.05	0.09	0.32	0.32	0.27	0.29
13	0.75	0.23	0.32	0.35	0.11	0.20	0.29	0.31	0.25	0.32	0.35	0.36	0.07	0.13	0.18	0.26	0.35	0.35	0.10	0.14	0.20	0.29	0.58	0.35
14	0.82	0.21	0.33	0.38	0.13	0.24	0.35	0.38	0.10	0.15	0.27	0.30	0.14	0.25	0.12	0.21	0.18	0.27	0.08	0.18	0.79	0.32	0.32	0.34
15	0.74	0.26	0.36	0.34	0.17	0.25	0.33	0.36	0.16	0.21	0.37	0.35	0.20	0.27	0.14	0.20	0.21	0.25	0.05	0.09	0.69	0.32	0.50	0.37
16	0.76	0.20	0.53	0.32	0.20	0.27	0.13	0.21	0.35	0.33	0.73	0.27	0.16	0.23	0.19	0.26	0.56	0.36	0.16	0.22	0.42	0.36	0.38	0.34
17	0.62	0.31	0.24	0.34	0.11	0.22	0.16	0.25	0.19	0.30	0.45	0.39	0.11	0.26	0.39	0.34	0.15	0.26	0.04	0.10	0.19	0.28	0.89	0.25
18	0.51	0.34	0.21	0.29	0.11	0.17	0.39	0.34	0.14	0.24	0.40	0.35	0.08	0.15	0.21	0.28	0.20	0.28	0.10	0.19	0.72	0.25	0.48	0.36
19	0.36	0.30	0.27	0.30	0.09	0.18	0.38	0.37	0.09	0.14	0.27	0.31	0.08	0.14	0.33	0.34	0.24	0.31	0.16	0.25	0.62	0.28	0.45	0.36
20	0.17	0.24	0.21	0.30	0.23	0.30	0.43	0.38	0.11	0.22	0.26	0.33	0.27	0.32	0.26	0.35	0.29	0.35	0.29	0.34	0.73	0.31	0.65	0.33
21	0.31	0.31	0.24	0.27	0.36	0.35	0.18	0.22	0.20	0.26	0.28	0.33	0.40	0.35	0.44	0.39	0.24	0.28	0.34	0.34	0.28	0.30	0.44	0.35
22	0.61	0.29	0.32	0.31	0.17	0.24	0.18	0.26	0.22	0.27	0.47	0.35	0.15	0.22	0.34	0.32	0.35	0.35	0.08	0.13	0.28	0.31	0.68	0.34
23	0.34	0.31	0.17	0.23	0.13	0.21	0.23	0.25	0.16	0.24	0.31	0.34	0.14	0.23	0.22	0.29	0.23	0.28	0.10	0.16	0.27	0.33	0.47	0.35
24	0.47	0.34	0.27	0.31	0.33	0.35	0.25	0.30	0.12	0.19	0.27	0.30	0.33	0.33	0.32	0.35	0.41	0.37	0.23	0.27	0.54	0.34	0.49	0.33
25	0.50	0.34	0.33	0.28	0.20	0.26	0.32	0.31	0.15	0.22	0.27	0.31	0.19	0.24	0.30	0.30	0.42	0.36	0.16	0.24	0.43	0.37	0.47	0.36
26	0.37	0.28	0.31	0.31	0.34	0.35	0.27	0.32	0.20	0.28	0.38	0.33	0.43	0.34	0.33	0.36	0.51	0.35	0.49	0.36	0.53	0.33	0.41	0.32
27	0.23	0.19	0.20	0.25	0.20	0.27	0.24	0.32	0.10	0.16	0.22	0.28	0.23	0.29	0.38	0.37	0.19	0.29	0.23	0.30	0.33	0.33	0.35	0.35
28	0.39	0.31	0.21	0.27	0.15	0.25	0.28	0.33	0.15	0.22	0.34	0.32	0.23	0.29	0.28	0.31	0.37	0.36	0.18	0.25	0.34	0.33	0.63	0.33
29	0.48	0.31	0.30	0.33	0.23	0.30	0.15	0.23	0.26	0.30	0.45	0.31	0.26	0.29	0.34	0.34	0.32	0.35	0.20	0.27	0.18	0.27	0.50	0.34

(continued)

(continued)

Stim #	Fusion		Gas		Liquid		Solid		Clouds		Wind		Water		Webs		Galaxies		Crystals		Machinery		Herds/ Crowds /Swarms	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
30	0.62	0.32	0.37	0.32	0.21	0.29	0.21	0.26	0.30	0.34	0.52	0.33	0.23	0.28	0.17	0.22	0.34	0.33	0.12	0.17	0.31	0.32	0.78	0.25
31	0.44	0.30	0.26	0.27	0.19	0.30	0.23	0.30	0.23	0.29	0.38	0.31	0.18	0.27	0.35	0.35	0.36	0.37	0.11	0.18	0.19	0.26	0.51	0.31
32	0.25	0.28	0.25	0.31	0.18	0.26	0.19	0.26	0.15	0.21	0.32	0.31	0.14	0.24	0.26	0.31	0.21	0.28	0.15	0.25	0.21	0.30	0.50	0.36
33	0.28	0.27	0.24	0.29	0.34	0.33	0.29	0.33	0.20	0.24	0.33	0.31	0.41	0.35	0.38	0.31	0.40	0.33	0.67	0.33	0.31	0.33	0.42	0.34
34	0.31	0.25	0.27	0.31	0.20	0.28	0.17	0.26	0.21	0.27	0.35	0.33	0.25	0.27	0.36	0.31	0.33	0.30	0.31	0.32	0.18	0.26	0.45	0.36
35	0.77	0.24	0.41	0.35	0.10	0.17	0.31	0.35	0.30	0.32	0.51	0.36	0.09	0.12	0.21	0.30	0.38	0.34	0.11	0.20	0.52	0.36	0.43	0.36
36	0.79	0.20	0.33	0.35	0.25	0.32	0.28	0.32	0.24	0.30	0.41	0.33	0.18	0.25	0.15	0.24	0.68	0.34	0.33	0.36	0.38	0.37	0.14	0.22
37	0.62	0.36	0.31	0.34	0.22	0.31	0.19	0.27	0.43	0.37	0.36	0.32	0.22	0.32	0.20	0.30	0.41	0.40	0.27	0.32	0.06	0.14	0.51	0.41
38	0.36	0.29	0.15	0.26	0.16	0.23	0.22	0.30	0.11	0.20	0.23	0.29	0.15	0.24	0.19	0.30	0.15	0.26	0.29	0.37	0.21	0.29	0.90	0.22
39	0.53	0.31	0.28	0.30	0.34	0.34	0.26	0.30	0.24	0.29	0.40	0.33	0.35	0.32	0.29	0.33	0.43	0.33	0.34	0.32	0.24	0.30	0.39	0.32
40	0.31	0.29	0.23	0.25	0.32	0.34	0.29	0.30	0.31	0.32	0.48	0.32	0.34	0.34	0.32	0.32	0.50	0.35	0.68	0.30	0.26	0.28	0.29	0.29