

Integration of Acoustical Information in the Perception of Impacted Sound Sources: The Role of Information Accuracy and Exploitability

Supplemental Online Materials

Bruno L. Giordano
McGill University

Davide Rocchesso
IUAV University of Venice

Stephen McAdams
McGill University

Acoustical features

Acoustical features were extracted using the methodology detailed in Giordano and McAdams (2006). A simulation of the processing that takes place in the peripheral auditory system produced the time-varying power at the output of a set of cochlear filters (temporal resolution: 44,100 Hz). The center frequency of the cochlear filters (range: 30-16,000 Hz) was uniformly spaced on a frequency scale derived from measures of the masked detection thresholds in normal-hearing listeners, the ERB-rate scale (Moore & Glasberg, 1983). This scale reflects the spacing of auditory filters along the basilar membrane. A first descriptor extracted from this representation was $\tan \phi_{\text{aud}}$, a unitless measure of the damping of vibration in struck solids (Wildes & Richards, 1988), associated with human judgments of sounding-object materials (cf. Giordano & McAdams, 2006, and references therein). Intuitively, $\tan \phi_{\text{aud}}$ captures the rate of energy decay in the most intense spectral components of the signal: the higher $\tan \phi_{\text{aud}}$, the faster the energy decay. More specifically, for each of the cochlear filters, linear regression is used to extract a damping factor for the power at the output of the cochlear filter. The damping factor is the inverse of the time needed for the output power to decay to $1/e$ of its initial value. The damping factors thus computed are then divided by the center frequency of the cochlear filters. The average of these values, weighted by the overall power in output from the cochlear filters gives the final value of $\tan \phi_{\text{aud}}$.

The temporal resolution of the energy at the output of each cochlear filter was subsequently decreased to 100 Hz, where 10 ms corresponds roughly to the temporal window for loudness integration (Plack & Moore, 1990). In a second step, the down-sampled energy output from the cochlear filters was raised to the power of 0.25. This yields an approximate measure of the loudness within each cochlear filter (Hartmann, 1997, p.66), otherwise termed specific loudness following Zwicker and Fastl (1999). Finally, the time-

varying loudness and spectral center of gravity (SCG) were defined as the sum of the specific loudnesses and as the specific-loudness-weighted average frequency on the ERB-rate scale, respectively. Notably, SCG captures the auditory attribute of brightness, a principal dimension of timbre (Grey & Gordon, 1978; McAdams, Winsberg, Donnadieu, De Soete, & Krimphoff, 1995). The measurement unit for loudness was termed pseudo-sones (p.s.), because it was calculated without taking into account the actual presentation levels. The time-varying loudness and SCG for one of the sounds in the database is shown in Figure 1.

The duration of the signal, Dur , was defined as the temporal extent during which loudness was above a fixed threshold (0.2 pseudo-sones), established from an analysis of the loudness of the background noise. As a term of comparison, the average of the time-varying loudness for each of the sounds in the database ranged from 0.35 for the smallest steel plate struck with the pine hammer to 1.63 pseudo-sones for the medium-sized plexiglas plate struck with the steel hammer. The grand average was 0.80 pseudo-sones. Four loudness descriptors were derived: the attack value, Lou_{att} (the average loudness over the first 10 ms of the signal), the average value over the whole duration, Lou_{mea} , and the slope of the initial and final portions of the temporal function of loudness, $Lou_{\text{s}11}$ and $Lou_{\text{s}12}$, respectively. Three SCG-related descriptors were extracted: the attack value, SCG_{att} (the average SCG over the first 10 ms of the signal), the average value over the whole duration, SCG_{mea} , and the slope of the initial portion of the temporal function of SCG, $SCG_{\text{s}10}$. Both the SCG and loudness slope measures were extracted by means of linear regression over a portion of the temporal function (see Figure 1). Finally, the frequency of the lowest spectral component, F , was estimated from the Fast Fourier Transform of the first 512 samples of the signal, starting from onset (Hanning window). Longer windows, affording a higher frequency resolution, could not be used, because no significant spectral peak would have emerged for the shortest and weaker signals (e.g., the plexiglas plate struck with the pine hammer). F was defined as the lowest-frequency component with an amplitude peak exceeding a fixed spectral level threshold, estimated from the spectral analysis of the 250 ms of background noise preceding each of the recorded signals. The spectral level for the extraction of F was therefore de-

Correspondence concerning this article should be addressed to Bruno L. Giordano, Schulich School of Music, McGill University, 555 Sherbrooke Street West, H3A 1E3, Montréal, Québec, Canada. E-mail: bruno.giordano@music.mcgill.ca.

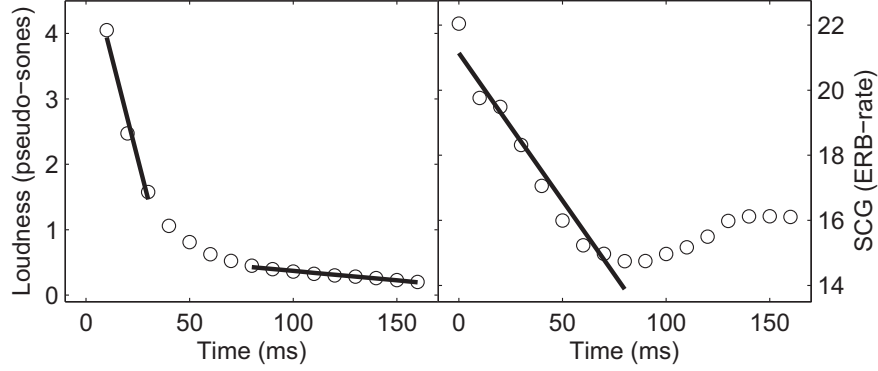


Figure 1. Time-varying loudness (left panel) and spectral center of gravity SCG (right panel) of the sound generated by striking a 900 cm² oak plate with an aluminum hammer. The solid lines show the regression functions used to extract the slope measures of the temporal rate of change of both time-varying acoustical features: Lou_{s11} and Lou_{s12} , leftmost and rightmost solid lines in left panel, respectively, and SCG_{s10} , solid line in right panel.

finned as 3 dB (decibels) higher than the maximum spectral amplitude across all background noise samples.

Sound synthesis model for stimuli in Experiment 3

The stimuli investigated in Experiment 3 were generated using a model of an inertial mass striking a resonating bar. An implementation originally proposed by Hunt and Crossley (1975), widely used in applied mechanics and robotics (Marhefka & Orin, 1999), and recently proposed for sound synthesis (Avanzini & Rocchesso, 2001) was used. In the model, the contact force is expressed as

$$f(x(t), v(t)) = \begin{cases} Kx(t)^\alpha + \lambda x(t)^\alpha \cdot v(t) = Kx(t)^\alpha (1 + \mu v(t)) & x > 0, \\ 0 & x \leq 0, \end{cases} \quad (1)$$

where $v(t) = \dot{x}(t)$ is the compression velocity, and K and α are the force stiffness coefficient and a geometry-dependent exponent, respectively. The parameter λ is a damping weight, and $\mu = \lambda/K$ is a mathematically convenient term called the viscoelastic characteristic by Marhefka and Orin (1999).

The impact model (Equation 1) can be used as a coupling mechanism between two modal resonators. For the purposes of this study, a simplified configuration was used, in which only one of the two objects actually resonates, the other being just an inertial mass whose displacement is indicated by $x^{(h)}$. According to modal analysis, the resonator is described through equations in which the variables $x_j^{(r)}$ are referred to as the modal displacements. Each mode obeys a second-order oscillator equation. Assuming the resonating object has $N^{(r)}$ modes, its displacement at a given point k is given by a linear combination of the modal displacements: $\sum_{j=1}^{N^{(r)}} t_{kj}^{(r)} x_j^{(r)}$. Assuming that the interaction occurs at point m of the resonator, the continuous-time equations of the coupled system

are given by:

$$\begin{cases} \ddot{x}^{(h)} = \frac{1}{m^{(h)}} (f_e^{(h)} + f), \\ \ddot{x}_j^{(r)} + g_j^{(r)} \dot{x}_j^{(r)} + [\omega_j^{(r)}]^2 x_j^{(r)} = \frac{1}{m_{jm}^{(r)}} (f_e^{(r)} - f) & (\text{for } j = 1 \dots N^{(r)}), \\ x = x_m = \sum_{j=1}^{N^{(r)}} t_{mj}^{(r)} x_j^{(r)} - t^{(h)} x^{(h)}, \\ v = v_m = \sum_{j=1}^{N^{(r)}} t_{mj}^{(r)} \dot{x}_j^{(r)} - t^{(h)} \dot{x}^{(h)}, \\ f(x, v) = \begin{cases} Kx(t)^\alpha + \lambda x(t)^\alpha \cdot v(t) & x > 0, \\ 0 & x \leq 0, \end{cases} \end{cases} \quad (2)$$

where the parameters $\omega^{(r)}$ and $g^{(r)}$ are the oscillator center frequencies and damping coefficients, respectively. The parameters $1/m^{(r)}$ control the ‘‘inertial’’ properties of the modal oscillators ($m^{(r)}$ has the dimension of mass). The terms $f_e^{(h)}$, $f_e^{(r)}$ represent external forces.

The continuous-time system (2) is discretized using the one-step Adams-Moulton method (Lambert, 1993), also known as bilinear transformation. The resulting discrete-time system appears as a parallel bank of second-order low-pass resonant filters, each accounting for one specific mode of the resonator. Details about the discrete-time system have been discussed elsewhere (Rocchesso & Fontana, 2003) and will not be addressed here.

Each mode is characterized by its decay time t_e (time to reduce the amplitude by a factor e), computed according to the notions of internal and external damping (van den Doel & Pai, 1998) as

$$\frac{1}{t_e} = \frac{f_i}{\tau_d} + \frac{1}{\tau_{ext}} = \pi f_i \tan \phi + \frac{1}{\tau_{ext}}, \quad (3)$$

where f_i is the modal center frequency, $\tan \phi$ is the internal friction parameter (Wildes & Richards, 1988; Klatzky, Pai, & Krotkov, 2000), and $1/\tau_{ext}$ is the external friction parameter.

Avanzini and Rocchesso (2001) derived an equation that relates the contact time τ to the physical parameters of the contact model, in the special case where the resonator is a rigid wall (i.e., it does not resonate at all):

$$\tau = \left(\frac{m^{(h)}}{K}\right)^{\frac{1}{\alpha+1}} \cdot \left(\frac{\mu^2}{\alpha+1}\right)^{\frac{\alpha}{\alpha+1}} \cdot \int_{v_{out}}^{v_{in}} \frac{dv}{(1+\mu v) \left[-\mu(v-v_{in}) + \log\left|\frac{1+\mu v}{1+\mu v_{in}}\right|\right]^{\frac{\alpha}{\alpha+1}}}. \quad (4)$$

It can easily be shown that the power-law dependence $t_0 \sim (m^{(h)}/K)^{1/(\alpha+1)}$ holds. In order to see how the contact time varies when the resonator is not perfectly rigid, numerical simulations were performed (Avanzini & Rocchesso, 2001), and τ was always higher than the value predicted by equation (4) due to the compliance of the struck object.

The model described above was implemented as indicated in Avanzini, Rath, and Rocchesso (2002). For the purpose of the present investigation, the resonator was set to have $N^{(r)} = 5$ modes. Modal frequencies were tuned according to the most prominent resonances of a clamped bar (Fletcher & Rossing, 1991), i.e., were multiples of the lowest resonant frequency F by $\{1, 6.26, 17.54, 34.37, 56.82\}$. Stimuli were synthesized varying the parameters F , $\tan \phi$ and K . All other model parameters were kept constant for all the experimental stimuli: the hammer mass $m^{(h)}$ was set to 0.5 kg; the geometry-dependent exponent α was set to 1.5; the interaction damping λ was set to 0 kg/m $^{\alpha}$ s; the strike velocity $\dot{x}^{(h)}(t=0)$ was set to -5 m/s; the external friction τ_{ext} was set to 0.5 s. It should be noted that the geometry-dependent exponent α was set as for contacting spheres in Hertz's theory (Landau & Lifshitz, 1981), and that the value chosen for the interaction damping parameter λ characterizes a lossless interaction.

Supplemental tables

The following tables provide details on the properties of the investigated stimulus sets. Table 1 reports the mechanical properties of the investigated hammer and sounding object materials. Table 2 shows the monotone association between the acoustical features of the sounds in the database, as estimated using the robust Spearman rank correlation coefficient. Significance levels for these correlations were computed considering only the N non-outlying points (minimum $N=126$, average $N=137$, $N\text{ SD}=5.4$). Tables 3-5 detail the mechanical and acoustical properties of the stimuli used in Experiments 1-3.

References

- Avanzini, F., Rath, M., & Rocchesso, D. (2002). Physically-based audio rendering of contact. In *Proceedings of the IEEE International Conference on Multimedia & Expo* (pp. 445–448). Lausanne, Switzerland.
- Avanzini, F., & Rocchesso, D. (2001). Modeling collision sounds: Non-linear contact force. In *Proceeding of the COST-G6 Conference on Digital Audio Effects PROC (DAFx01)* (pp. 61–66). Limerick, Ireland.
- Fletcher, N. H., & Rossing, T. D. (1991). *The physics of musical instruments*. New York, NY: Springer-Verlag.
- Giordano, B. L., & McAdams, S. (2006). Material identification of real impact sounds: effects of size variation in steel, glass, wood and plexiglass plates. *Journal of the Acoustical Society of America*, 119, 1171–1181.
- Grey, J. M., & Gordon, J. W. (1978). Perceptual effects of spectral modifications on musical timbres. *Journal of the Acoustical Society of America*, 63, 1493–1500.
- Hartmann, W. M. (1997). *Signals, sound and sensation*. Woodbury, NY: AIP Press.
- Hunt, K. H., & Crossley, F. R. E. (1975). Coefficient of restitution interpreted as damping in vibroimpact. *ASME Journal of Applied Mechanics*, 42, 440–445.
- Klatzky, R. L., Pai, D. K., & Krotkov, E. P. (2000). Perception of material from contact sounds. *Presence: Teleoperators and Virtual Environment*, 9, 399–410.
- Lambert, J. D. (1993). *Numerical methods for ordinary differential systems*. Chichester, UK: John Wiley & Sons.
- Landau, L., & Lifshitz, E. M. (1981). *Theory of elasticity*. London, UK: Pergamon Press.
- Marhefka, D. W., & Orin, D. E. (1999). A compliant contact model with nonlinear damping for simulation of robotic systems. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans*, 29, 566–572.
- McAdams, S., Winsberg, S., Donnadieu, S., De Soete, G., & Krimphoff, J. (1995). Perceptual scaling of synthesized musical timbres: Common dimensions, specificities, and latent subject classes. *Psychological Research*, 58, 177–192.
- Moore, B. C. J., & Glasberg, B. R. (1983). Suggested formulae for calculating auditory-filter bandwidths and excitation patterns. *Journal of the Acoustical Society of America*, 74, 750–753.
- Plack, C. J., & Moore, B. C. J. (1990). Temporal window shape as a function of frequency and level. *Journal of the Acoustical Society of America*, 87, 2178–2187.
- Rocchesso, D., & Fontana, F. (2003). *The sounding object*. Firenze, Italy: Mondo Estremo.
- van den Doel, K., & Pai, D. K. (1998). The sounds of physical shapes. *Presence*, 7, 382–395.
- Wildes, R., & Richards, W. (1988). Recovering material properties from sound. In W. Richards (Ed.), *Natural computation* (pp. 356–363). Cambridge, MA: MIT Press.
- Zwicker, E., & Fastl, H. (1999). *Psychoacoustics: facts and models* (2nd ed.). New York, NY: Springer-Verlag.

Table 1
Mechanical Properties of The Hammer and Sounding-Object Materials

Material	Density (kg/m ³)	D ₁ (GPa)	D ₂ (GPa)	D ₃ (GPa)	D ₄ (GPa)	Hardness
Aluminum	2658.74	6.06	4.14	6.06	7.97	6
Ceramic	2124.79	1.71	0.22	1.71	3.19	4
Glass	2485.54	5.90	2.74	5.90	9.05	5
Oak	794.71	1.46	0.51	0.49	0.37	3
Pine	676.08	1.47	0.47	0.42	0.35	1
Plexiglas	1186.22	0.42	0.30	0.42	0.54	2
Steel ₁	7751.85	17.33	9.32	17.33	25.35	7
Steel ₂	7824.24	18.17	10.06	18.17	26.27	8

Note. D = rigidity coefficient; GPa = Giga Pascal. Steel₁ was used for the hammer and for the two smaller steel plates; Steel₂ was used for the larger plate.

Table 2
Robust Spearman Rank Correlation Between the Features of the Sounds in the Database of Impacted Sound Sources

Feature	$\tan \phi_{\text{aud}}$	Dur	F	Lou _{att}	Lou _{mea}	Lou _{s11}	Lou _{s12}	SCG _{att}	SCG _{mea}	SCG _{slo}
$\tan \phi_{\text{aud}}$	–	–.95 **	–.26 **	–.13	.70 **	–.62 **	–.92 **	–.81 **	–.69 **	–.84 **
Dur		–	.16	.00	–.81 **	.71 **	.99 **	.71 **	.48 **	.76 **
F			–	–.51 **	–.31 **	.35 **	.14	.26 **	.72 **	.39 **
Lou _{att}				–	.62 **	–.92 **	–.10	.34 **	–.09	.37 **
Lou _{mea}					–	–.87 **	–.88 **	–.42 **	–.45 **	–.65 **
Lou _{s11}						–	.70 **	.25 **	.35 **	.51 **
Lou _{s12}							–	.66 **	.38 **	.72 **
SCG _{att}								–	.83 **	.63 **
SCG _{mea}									–	.61 **
SCG _{slo}										–

Note. Dur = duration; F = frequency; Lou = loudness; SCG = Spectral Center of Gravity; att = attack; mea = mean; s11 = initial slope; s12 = final slope; slo = slope. ** $p < .01$; $df \geq 126$.

Table 3
Acoustical Features for the Stimuli Investigated in Experiment 1.

MatSO	MatH	SizeSO (cm ²)	tan ϕ_{aud} $\times 10^{-3}$	Dur (s)	F (Hz)	Lou _{att} (p.s.)	Lou _{mea} (p.s.)	Lou _{s11} (p.s./s)	Lou _{s12} (p.s./s)	SCG _{att} (ERB-rate)	SCG _{mea} (ERB-rate)	SCG _{slo} (ERB-rate/s)
Oak	Oak	229.50	21.28	0.08	2153.32	2.82	0.93	-80.17	-5.50	21.28	18.78	-52.59
Oak	Cer	229.50	20.38	0.08	2153.32	3.12	1.00	-92.13	-5.67	21.71	19.31	-61.44
Oak	Ste ₁	229.50	13.88	0.11	775.20	4.05	1.14	-101.76	-3.67	21.41	19.68	-42.72
Oak	Oak	894.00	19.00	0.20	516.80	3.12	0.74	-65.06	-1.45	20.70	16.00	-72.89
Oak	Cer	894.00	14.74	0.18	516.80	3.59	0.83	-80.34	-1.70	22.26	16.50	-90.21
Oak	Ste ₁	894.00	18.51	0.22	516.80	4.68	0.94	-106.86	-1.36	21.32	16.05	-77.67
Cer	Oak	224.25	8.79	0.26	602.93	2.47	0.51	-53.11	-0.87	21.50	19.66	-29.88
Cer	Ste ₁	224.25	9.37	0.25	1291.99	3.63	0.60	-94.80	-0.98	23.91	20.18	-55.32
Cer	Oak	900.00	6.04	0.38	344.53	2.56	0.55	-48.90	-0.86	21.93	16.87	-30.72
Cer	Cer	900.00	5.97	0.33	344.53	4.20	0.74	-91.01	-1.12	24.83	17.57	-45.15
Cer	Ste ₁	900.00	5.65	0.43	344.53	6.39	0.88	-142.15	-0.88	25.18	17.70	-30.76
Ste ₁	Oak	225.00	1.78	0.69	2583.98	1.39	0.36	-18.66	-0.36	23.21	23.66	-131.36
Ste ₁	Cer	225.00	1.22	0.92	2583.98	2.75	0.50	-39.32	-0.29	26.73	25.57	-7.06
Ste ₂	Cer	900.00	0.70	0.98	689.06	3.50	0.97	-14.42	-0.70	26.86	20.58	-10.85
Ste ₂	Ste ₁	900.00	0.54	0.98	689.06	4.62	1.15	-31.61	-0.84	28.04	20.28	-10.74

Note. Mat = hardness; SO = sounding object; H = hammer; Dur = duration; F = frequency; Lou = loudness; SCG = Spectral Center of Gravity; att = attack; mea = mean; s11 = initial slope; s12 = final slope; slo = slope; p.s. = pseudo-sones; ERB = Equivalent Rectangular Bandwidth; Cer = ceramic; Ste₁ = flexible steel; Ste₂ = stiff steel.

Table 4
Acoustical Features for the Stimuli Investigated in Experiment 2.

MatSO	MatH	SizeSO (cm ²)	tan ϕ_{aud} $\times 10^{-3}$	Dur (s)	F (Hz)	Lou _{att} (p.s.)	Lou _{mea} (p.s.)	Lou _{s11} (p.s./s)	Lou _{s12} (p.s./s)	SCG _{att} (ERB-rate)	SCG _{mea} (ERB-rate)	SCG _{s10} (ERB-rate/s)
Alu	Cer	224.62	7.39	0.20	2670.12	2.34	0.60	-52.41	-1.82	25.22	25.39	-167.46
Gla	Ple	225.00	7.83	0.12	2583.98	2.57	0.84	-57.92	-4.39	24.58	23.25	-96.14
Oak	Pin	449.44	24.22	0.09	689.06	3.45	1.16	-86.66	-6.78	20.74	17.66	-69.26
Oak	Alu	894.00	15.50	0.17	516.80	4.04	0.99	-89.59	-2.46	22.06	15.95	-93.14
Pin	Oak	223.46	18.40	0.08	1119.73	2.84	1.05	-74.25	-6.75	20.82	19.10	-47.55
Pin	Pin	223.46	21.48	0.07	1119.73	2.90	1.17	-78.45	-9.85	21.31	19.14	-53.16
Pin	Oak	886.50	18.63	0.15	602.93	2.42	0.76	-54.56	-2.39	19.70	16.10	-54.83
Pin	Ste1	886.50	22.57	0.12	689.06	3.43	1.10	-82.60	-4.14	19.97	16.62	-49.34
Ple	Gla	225.00	19.61	0.07	1119.73	3.47	1.15	-108.04	-8.12	23.40	20.39	-64.28
Ple	Ple	901.50	18.67	0.07	258.40	3.61	1.34	-97.58	-10.50	22.52	19.18	-60.03
Cer	Cer	224.25	7.83	0.24	602.93	3.66	0.71	-85.68	-1.10	23.18	19.85	-48.62
Cer	Alu	449.44	6.03	0.28	516.80	5.44	0.93	-128.06	-1.57	24.84	19.68	-42.97
Cer	Ple	449.44	5.49	0.24	689.06	4.10	0.85	-93.02	-1.62	23.82	19.42	-26.50
Cer	Ple	900.00	5.98	0.30	344.53	3.38	0.74	-68.12	-1.33	23.47	17.16	-37.05
Ste1	Ste1	225.00	1.34	0.58	2583.98	3.14	0.65	-53.40	-0.98	26.96	27.80	-3.92
Ste1	Alu	445.10	1.64	0.53	1291.99	2.66	0.72	-23.88	-0.99	27.26	26.91	-127.54
Ste1	Ste1	445.10	1.60	0.62	1291.99	3.10	0.86	-20.82	-1.02	27.23	26.21	-137.56
Ste2	Oak	900.00	0.67	0.98	689.06	2.06	0.81	-4.84	-0.63	23.52	19.22	-7.86

Note. Mat = hardness; SO = sounding object; H = hammer; Dur = duration; F = frequency; Lou = loudness; SCG = Spectral Center of Gravity; att = attack; mea = mean; s11 = initial slope; s12 = final slope; slo = slope; p.s. = pseudo-sones; ERB = Equivalent Rectangular Bandwidth; Alu = aluminum; Cer = ceramic; Gla = glass; Pin = pine; Ple = plexiglass; Ste1 = flexible steel; Ste2 = stiff steel.

Table 5
Synthesis Parameters and Acoustical Features for the Stimuli Investigated in Experiment 3.

$\tan \phi$ $\times 10^{-3}$	K ($N/m^{1.5}$)	$\tan \phi_{\text{aud}}$ $\times 10^{-3}$	Dur (s)	F (Hz)	Lou _{att} (p.s.)	Lou _{mea} (p.s.)	Lou _{s11} (p.s./s)	Lou _{s12} (p.s./s)	SCG _{att} (ERB-rate)	SCG _{mea} (ERB-rate)	SCG _{slo} (ERB-rate/s)
31.83	0.05	37.96	0.26	50.00	1.43	0.48	-16.86	-1.26	13.08	9.25	-43.09
31.83	2.24	33.03	0.21	50.00	5.42	1.15	-155.47	-2.36	16.20	10.88	-48.48
31.83	100.00	29.38	0.17	50.00	8.45	1.62	-307.63	-2.15	20.99	12.21	-89.58
7.96	0.05	11.53	0.64	50.00	1.50	0.51	-5.83	-0.61	13.18	9.50	-9.92
7.96	2.24	9.15	0.61	50.00	6.03	1.05	-79.62	-0.89	16.32	11.12	-12.00
7.96	100.00	7.89	0.56	50.00	10.59	1.31	-208.16	-0.84	21.03	11.87	-30.77
1.99	0.05	4.71	1.20	50.00	1.55	0.57	-2.32	-0.38	13.22	10.01	-2.67
1.99	2.24	3.29	1.38	50.00	6.27	1.14	-23.52	-0.45	16.36	11.90	-4.59
1.99	100.00	2.34	1.31	50.00	10.74	1.59	-54.01	-0.46	21.04	13.22	-9.47
31.83	0.05	34.97	0.20	200.00	1.24	0.53	-11.09	-2.36	13.70	10.39	-157.26
31.83	2.24	36.79	0.23	200.00	4.08	0.90	-123.86	-2.33	16.15	10.66	-90.57
31.83	100.00	35.58	0.19	200.00	7.32	1.18	-258.58	-2.38	21.65	11.65	-204.05
7.96	0.05	11.01	0.60	200.00	1.31	0.53	-3.73	-0.74	13.85	10.34	-18.16
7.96	2.24	10.17	0.69	200.00	4.65	0.85	-57.34	-0.76	16.39	10.69	-21.03
7.96	100.00	8.12	0.57	200.00	8.40	0.98	-247.30	-0.77	22.10	11.85	-45.75
1.99	0.05	5.11	1.26	200.00	1.37	0.54	-1.81	-0.35	13.92	10.35	-4.67
1.99	2.24	3.68	1.48	200.00	4.89	0.92	-16.27	-0.35	16.47	11.24	-6.37
1.99	100.00	2.15	1.22	200.00	9.57	1.15	-88.15	-0.38	22.25	13.09	-17.84
31.83	0.05	37.49	0.04	800.00	0.63	0.38	-18.25	-14.15	15.02	14.46	-110.05
31.83	2.24	32.98	0.08	800.00	3.81	1.37	-122.72	-12.44	16.29	15.90	-180.42
31.83	100.00	31.89	0.09	800.00	6.13	1.86	-176.43	-9.76	20.62	16.76	-274.37
7.96	0.05	10.27	0.09	800.00	0.66	0.34	-11.81	-3.13	15.22	16.00	-95.58
7.96	2.24	8.61	0.29	800.00	4.25	1.16	-43.96	-2.48	16.46	16.32	-144.78
7.96	100.00	8.45	0.31	800.00	6.83	1.55	-119.04	-2.43	21.08	16.74	-41.91
1.99	0.05	3.21	0.25	800.00	0.67	0.31	-5.63	-0.91	15.28	16.75	-179.01
1.99	2.24	2.73	0.88	800.00	4.41	1.14	-13.70	-0.83	16.52	16.35	-127.88
1.99	100.00	2.65	0.94	800.00	7.69	1.52	-39.42	-0.83	21.26	16.80	-11.78

Note. Dur = duration; F = frequency; Lou = loudness; SCG = Spectral Center of Gravity; att = attack; mea = mean; s11 = initial slope; s12 = final slope; slo = slope; p.s. = pseudo-sones; ERB = Equivalent Rectangular Bandwidth; SO = sounding object; H = hammer; Hard = hardness; Imp = hammer/sounding-object impact. Synthesis parameters are reported in the two leftmost columns and in the fifth column. Acoustical features are reported in the ten rightmost columns.