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MUSIC VS NOISE: A COMPARISON OF LOUDNESS ESTIMATES

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The aim of this study was to examine whether loudness estimates of music are performed according to the same principles as loudness judgements of non-musical sounds. For this purpose loudness estimates of short musical passages were compared with those of noise signals. Spectral energy distribution of noise was matched to that of music. The results show that loudness judgements of music and noise agree reasonably well. This finding suggests that loudness of musical tones may also be determined by means of objective methods for loudness calculation, which are employed in measurements of non-musical sounds.

1. Introduction

Variations of loudness in music are indicated by dynamic marks or levels (pianissimo, piano, mezzoforte, forte etc.). It has been demonstrated in a number of studies that, in most instruments, tones played at different dynamic levels – from "very soft" to "very loud" – differ not only in sound pressure, but also in spectral envelope [1, 2, 6, 8, 11]. When a tone is played louder, the amplitude of its higher-frequency partials increases relative to that of the lower frequency partials. Changes of the spectral envelope due to dynamic gradations are greatest in woodwinds and brass instruments. An example of sound spectra measured at different playing levels is given in Fig. 1. The higher harmonics of a French horn tone played pianissimo are very weak. As the dynamic level increases, so too does the sound level of the higher harmonics relative to that of the fundamental.

The musical dynamic marks do not specify loudness directly as a psychoacoustical magnitude. In common usage, pianissimo means "very soft", piano "soft", mezzoforte "moderately loud", and so on. In fact, the level of loudness corresponding to a given dynamic mark varies with respect to the instrument played [9, 10].

Reinecke [11] pointed out that spectral changes of sound associated with changes in playing level provide a cue for recognizing the dynamic level at which music is performed. This may be easily demonstrated by means of musical recordings. A musically

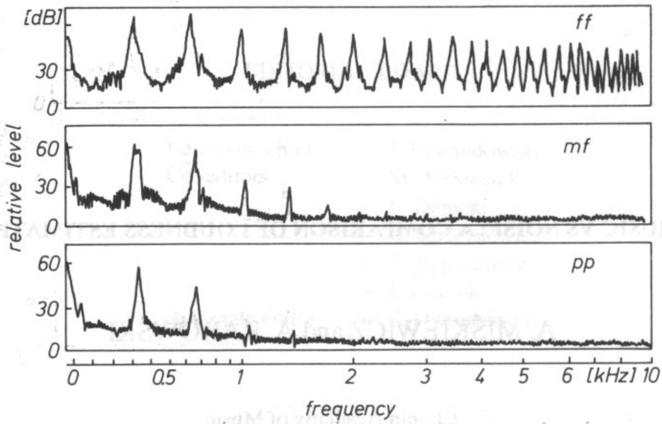


Fig. 1. Sound spectra of a horn at different playing levels, played note: F4, (from [8]).

competent listener is able to recognize the dynamic levels of music regardless the loudness level at which a recording is played back.

A great deal of research work has been carried out to examine the relationship between physical characteristics of sound and the magnitude of loudness. Investigations of loudness published so far have been carried out with non-musical stimuli. In the case of musical sounds, uncertainty arises as to whether loudness estimates of musical tones follow the same principles as loudness judgements of non-musical sounds. The difference between loudness evaluation of musical and non-musical sounds might be cognitive in origin, connected with the specific way in which the dynamic relations of music are perceived. When a musician is asked to judge the loudness of a passage of music, his responses might be influenced not only by the one-dimensional sensation of loudness, but also by implied musical dynamic levels.

The present experiment was conducted to examine whether any systematic differences occur between loudness judgments of musical and non-musical sounds. For this purpose loudness estimates of short musical passages were compared with loudness estimates of noise stimuli.

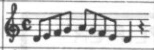
Loudness may be estimated from physical sound parameters. The validity of loudness calculation methods has not yet been tested for musical sounds. The present study provides data on the question of whether, or to what extent, methods for determining the loudness of noise may be applied to the tones of musical instruments.

2. Experimental procedure

Thirty music students estimated the loudness of short musical passages, wide-band noise with various spectral envelopes, and 1/3-octave band noise centered at 1 kHz. All stimuli were recorded on tape.

The musical passages were scale segments (see Table 1) played in various pitch registers on a viola, a clarinet and a trumpet. Three dynamic marks were used: pianis-

Table 1. Sound pressure levels of musical passages played back through a loudspeaker in the listening room.

scale segments		sound pressure level [dB SPL]								
		viola			clarinet			trumpet		
		pp	mf	ff	pp	mf	ff	pp	mf	ff
D_3		63.7	71.6	74.9						
A_3		66.0	74.2	77.0				65.4	77.8	84.5
D_4		60.5	69.4	72.0	67.3	74.1	78.2	68.4	78.3	85.2
A_4		58.1	65.1	67.3	66.9	74.7	79.6	70.9	81.5	87.3
D_5					74.9	80.0	82.7	72.6	83.0	88.4
A_5					74.5	78.5	82.1			

simo, mezzoforte and fortissimo. Recordings of musical examples were made in a live studio (reverberation time: 0.9–1.1 s in the range 250–4000 Hz), with a Studer A 810 tape machine. The cardioid condenser microphone (Neumann KM 84) used for recording was placed at a distance of 1.5 m from the performer.

The spectral energy distribution of the musical signals was analysed by means of apparatus shown in Fig. 2. The analysis involved measuring the sound pressure levels in 1/3–octave bands.

Next, wide-band noises were recorded, whose spectral energy distribution (sound pressure level in 1/3 octave bands) was matched to that of musical stimuli. A Brüel & Kjaer 5537 spectrum shaper was used for this purpose. Each noise matched one of the musical examples. The corresponding musical and noise signals had the same duration (approximately 4 seconds).

The experiment was carried out in individual listening sessions, by 30 subjects. The listeners judged loudness by the method of absolute magnitude estimation [4, 16], assigning to each of the stimuli a number which indicated the subjective magnitude of loudness. There was no limitation on the range of numbers: any positive number that seemed to be appropriate could be used. Subjects were told to concentrate on each judgment individually and not to be concerned with numbers assigned to preceding tones. Listeners had only 5 seconds between trials during which they wrote down the number on a prepared form. A relatively short time was chosen to minimize the probability of listeners judging stimuli relative to each other.

The stimuli were played back through a loudspeaker in a listening room. At the beginning of each listening session, prior to the main experiment, a preliminary test was presented in order to investigate whether the listeners performed loudness judgments in a similar way as reported in the literature. The test comprised eleven 1-second stimuli (1/3–octave band noises centered at 1 kHz), presented at sound pressure levels covering the range 50–90 dB SPL in 4–dB steps. The sequence of sound pressure levels was random and different for each listener.

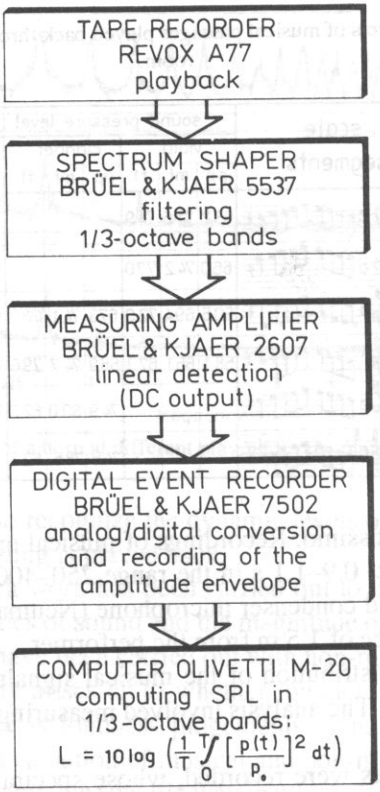


Fig. 2. Block diagram of apparatus used for measuring sound spectra of musical recordings.

The main test consisted of 3 series (viola, clarinet and trumpet) of 12 scale segments (4 pitch registers at 3 dynamic levels) and 3 series of the corresponding noise signals. The order of scale segments in each musical series was random (different for each listener) as was the order of series in each listening session.

It has been demonstrated in the literature that loudness estimates are susceptible to serial effects [e.g. 3, 5, 15]. In order to eliminate this source of bias, the sequence of noise signals within a series always replicated that of the corresponding musical stimuli. The whole test was presented to subjects only once and a listening session lasted about 25 minutes.

Table 1 specifies the sound pressure levels of stimuli presented in all six series. The sound pressure levels measured in 1/3-octave bands are shown in Figs. 3–5.

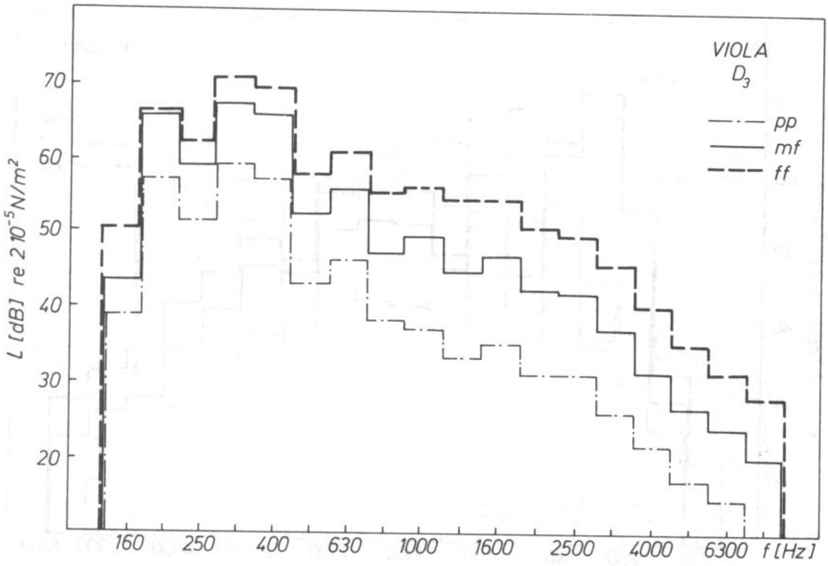


Fig. 3a. Sound pressure levels of scale segments D3 played on a viola, measured in 1/3–octave bands.

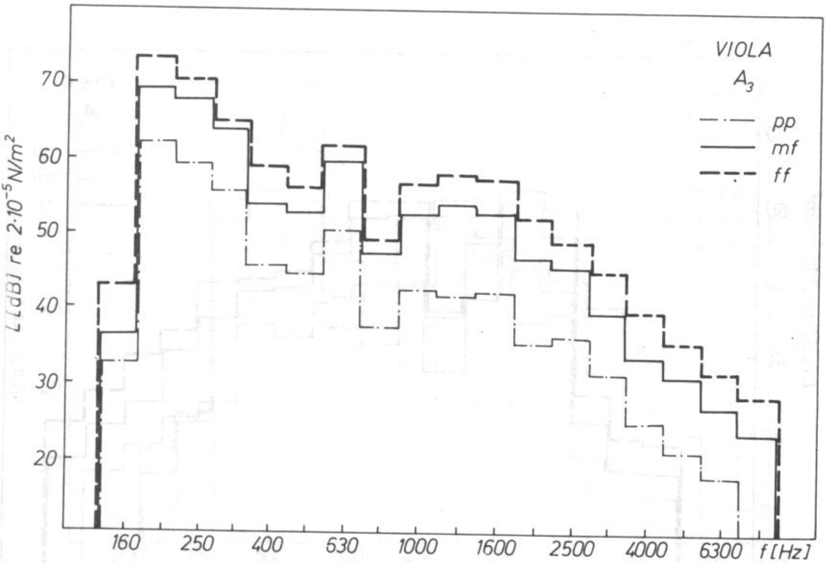


Fig. 3b. Sound pressure levels of scale segments A3 played on a viola, measured in 1/3–octave bands.

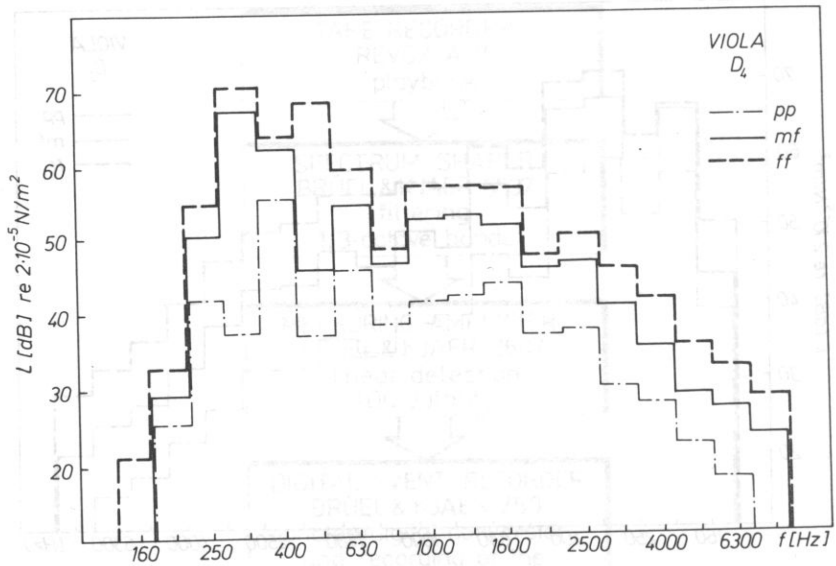


Fig. 3c. Sound pressure levels of scale segments D4 played on a viola, measured in 1/3–octave bands.

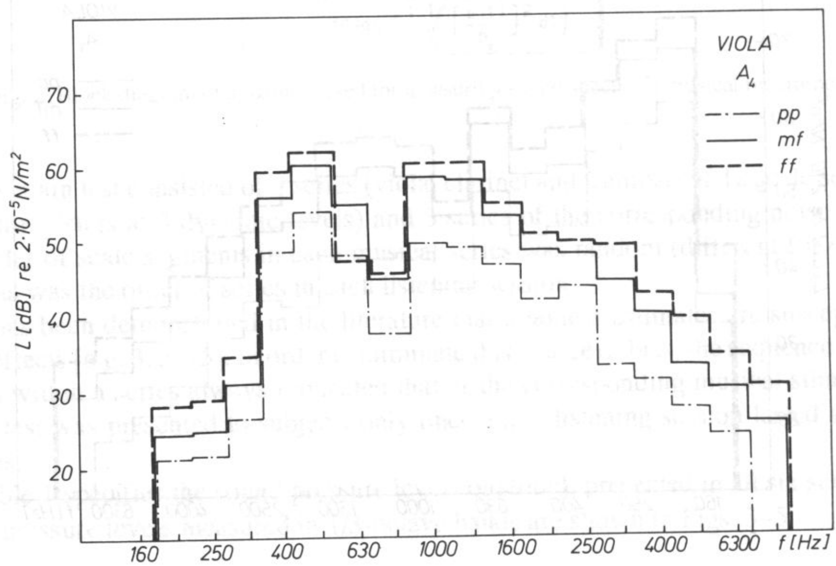


Fig. 3d. Sound pressure levels of scale segments A4 played on a viola, measured in 1/3–octave bands.

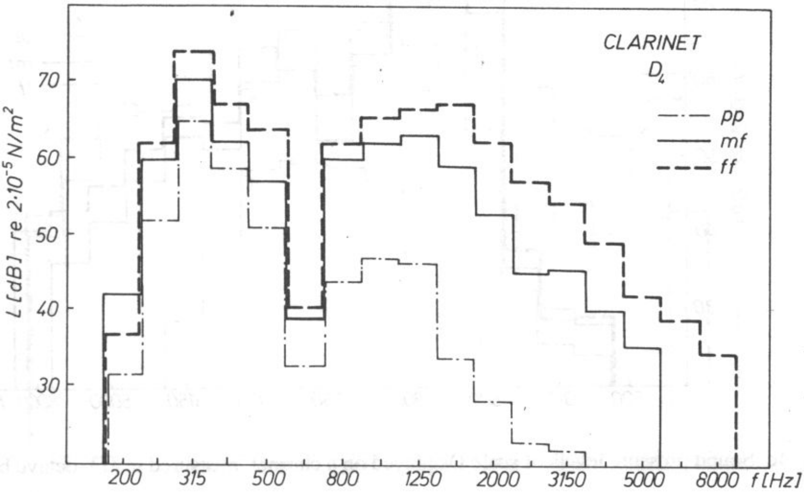


Fig. 4a. Sound pressure levels of scale segments D_4 played on a clarinet, measured in 1/3–octave bands.

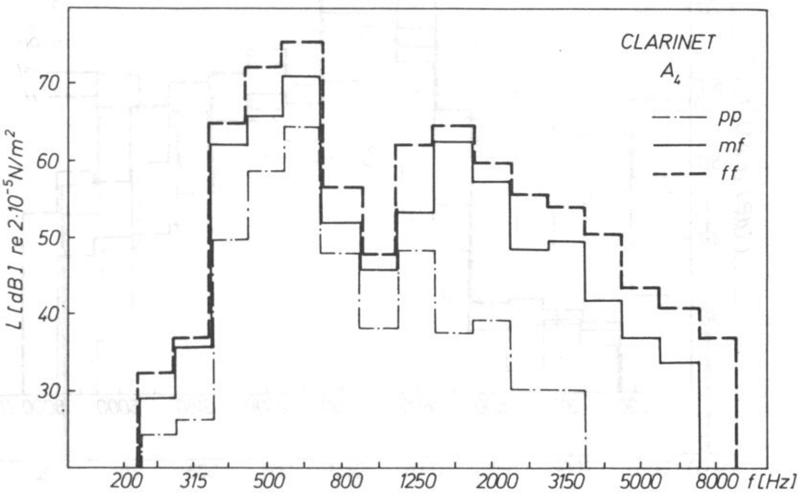


Fig. 4b. Sound pressure levels of scale segments A_4 played on a viola, measured in 1/3–octave bands.

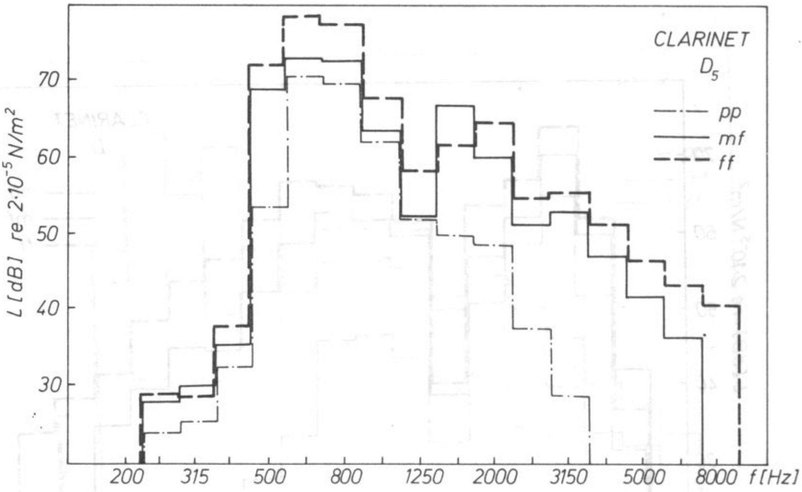


Fig. 4c. Sound pressure levels of scale D5 played on a clairnet, measured in 1/3–octave bands.

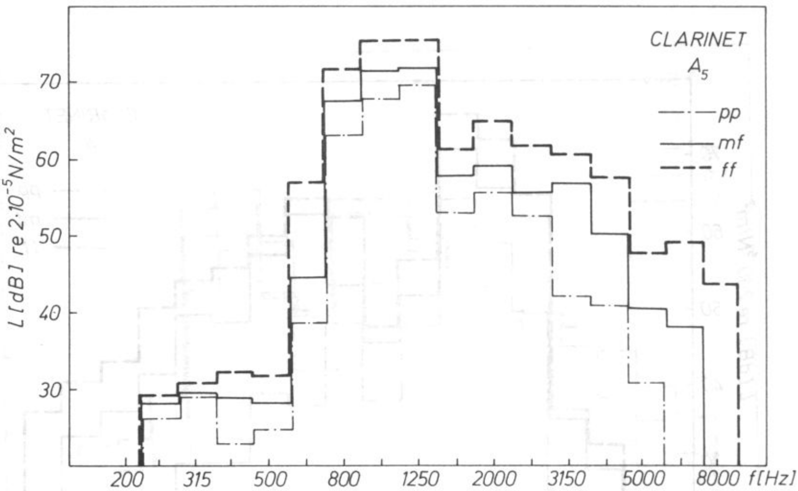


Fig. 4d. Sound pressure levels of scale segments played on a clairnet, measured in 1/3–octave bands.

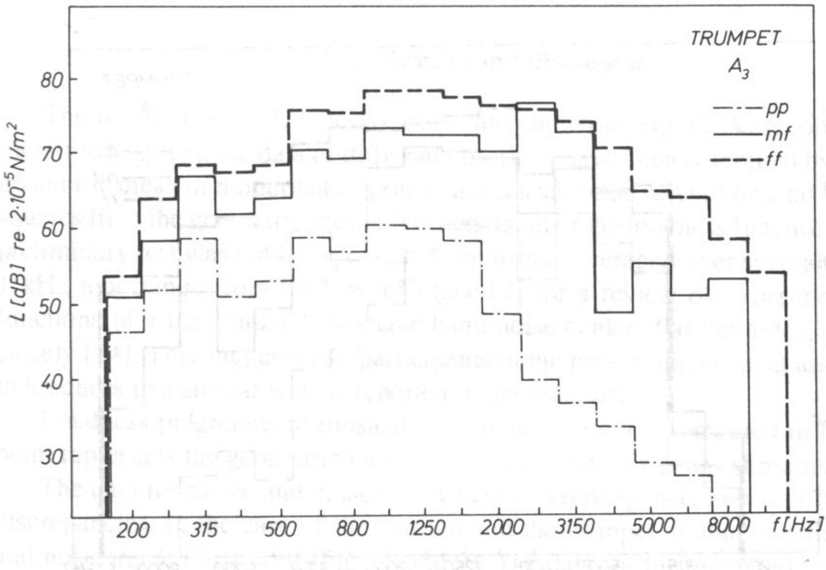


Fig. 5a. Sound pressure levels of scale A3 played on a trumpet, measured in 1/3–octave bands.

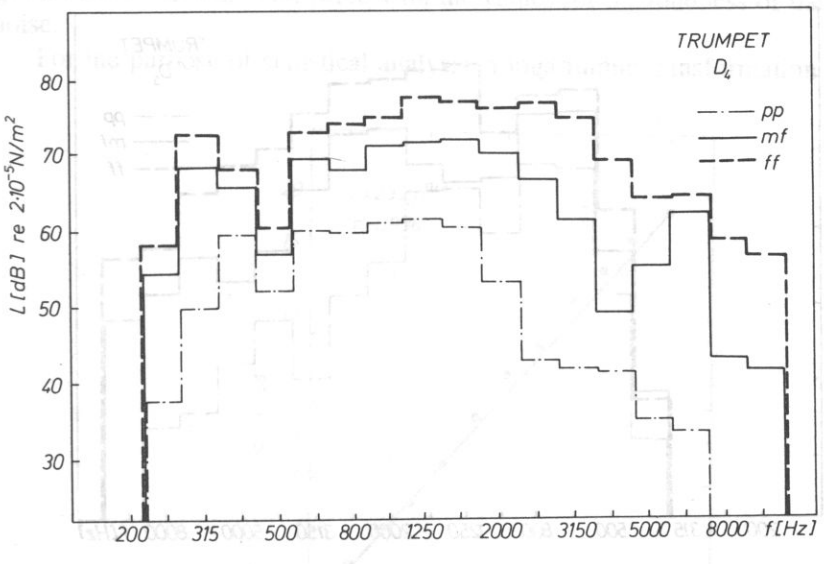


Fig. 5b. Sound pressure levels of scale D4 played on a trumpet, measured in 1/3–octave bands.

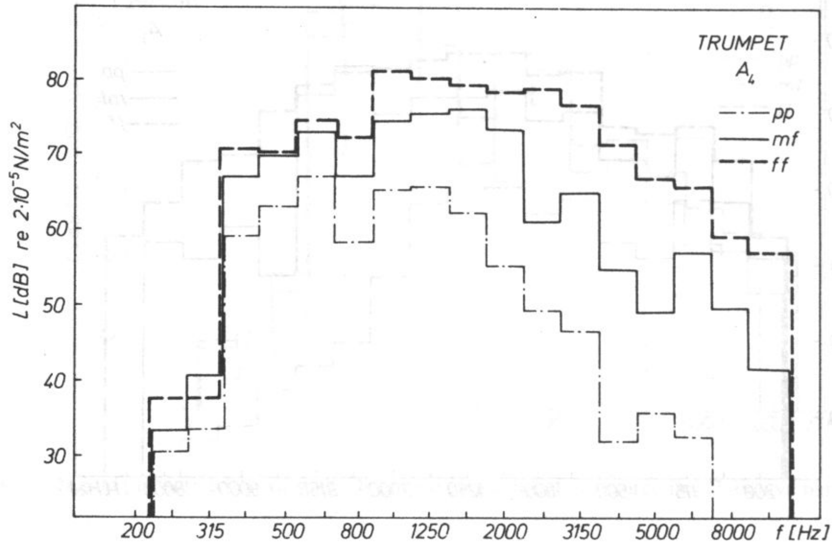


Fig. 5c. Sound pressure levels of scale segments A4 played on a trumpet, measured in 1/3–octave bands.

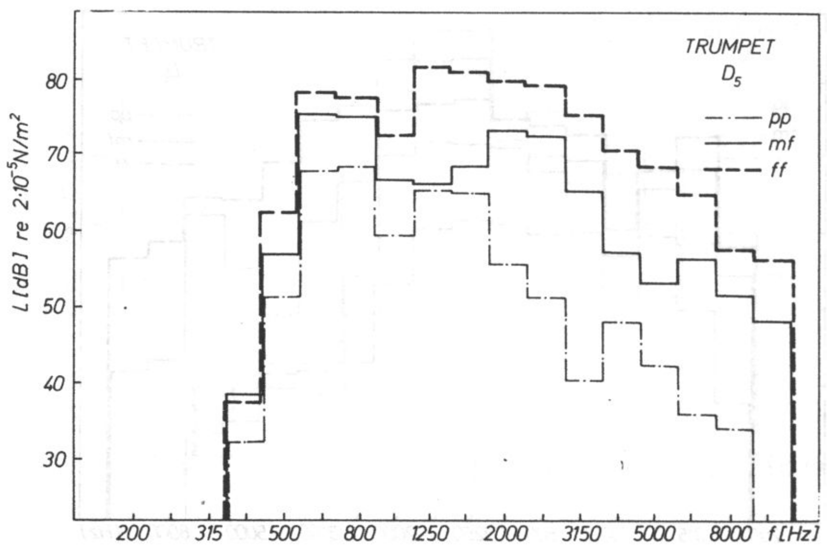


Fig. 5d. Sound pressure levels of scale segments D5 played on a trumpet, measured in 1/3–octave bands.

3. Results and discussion

The results for the 1/3–octave noise are shown in Fig. 6. As recommended in the literature [e.g. 13], the data of different observers have been combined by computing the geometric mean of numerical responses at each stimulus value. The straight line is a least squares fit to the geometric means. The exponent of the loudness function obtained in the preliminary test was 0.44. Exponents from results averaged over several observers for a 1 kHz tone range from 0.43 to 0.55 (see [7] for a review of experiments). Loudness functions of a tone and a 1/3–octave band noise centered at the tones frequency agree closely [14]. This suggests that participants in the present experiment assigned numbers to loudness in a similar way as reported in the literature.

Loudness judgments of musical stimuli and noise are compared in Figs. 7–9. Each point represents the geometric mean of 30 judgments of a given stimulus.

The data for music and noises show general convergence, however there are certain discrepancies. In the case of the clarinet and the trumpet, loudness estimates of music and noise agree fairly well (Figs. 8 and 9). The data for the viola and for noise are less convergent (Fig. 7).

In order to examine whether discrepancies between loudness estimates of music and noise are systematic and statistically significant, a *t*-test analysis was carried out. The geometric means of loudness estimates for each of the 12 musical passages played on a given instrument were compared with the values for the loudness of the corresponding noise.

For the purpose of statistical analysis, a logarithmic transformation was applied to

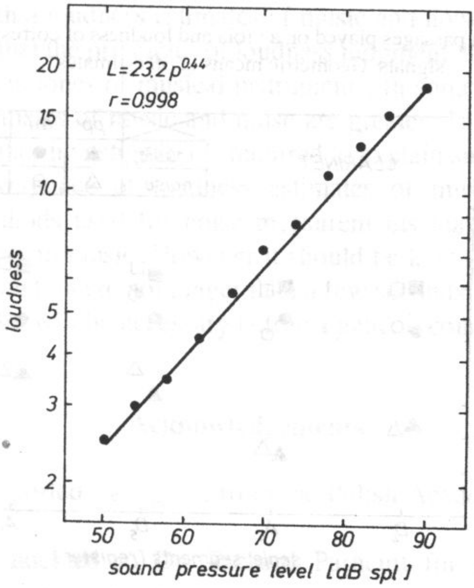


Fig. 6. Loudness of the 1/3–octave noise centered at 1000 Hz. Geometric means of 30 estimates.

the data. This made the distribution of numerical judgments approximately normal. The t-values were then computed on the transformed variable.

In case of viola and clarinet, the discrepancies between loudness estimates of music and noise were not statistically significant ($p < 0.25$). In case of the trumpet, most of the 12 noise signals were judged louder than the musical passages. The differences between loudness judgments of trumpet and noise were significant at a level of $p < 0.01$. The discrepancies between loudness estimates of trumpet and noise were nevertheless very small in magnitude (Fig. 9).

Differences between loudness estimates of music and noise were larger for some pairs of stimuli than for others. It may be assumed that those discrepancies result from differences in spectral structure between particular music and noise stimuli. Equally loud

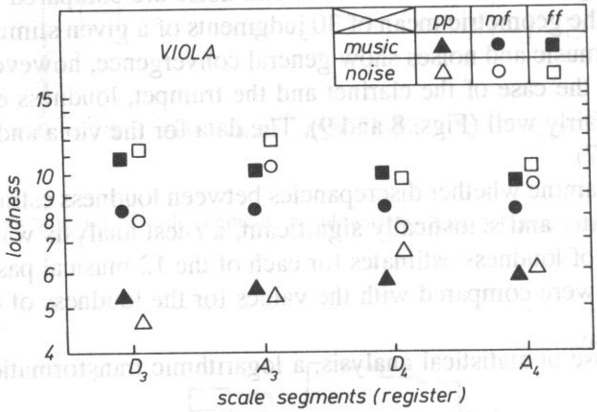


Fig. 7. Loudness of musical passages played on a viola and loudness of corresponding wide-band noise signals. Geometric means of 30 estimates.

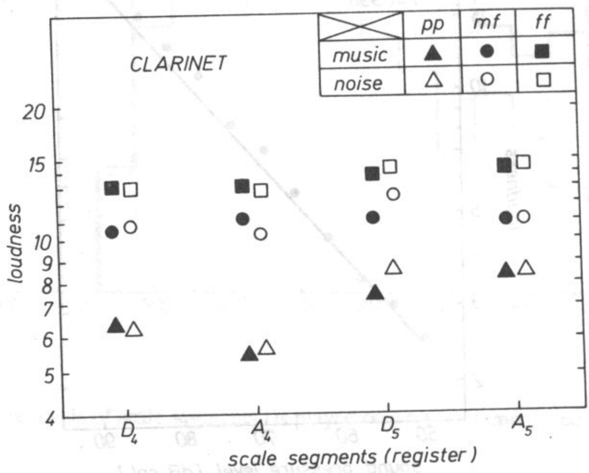


Fig. 8. Loudness of musical passages played on a clarinet and loudness of corresponding wide-band noise signals. Geometric means of 30 estimates.

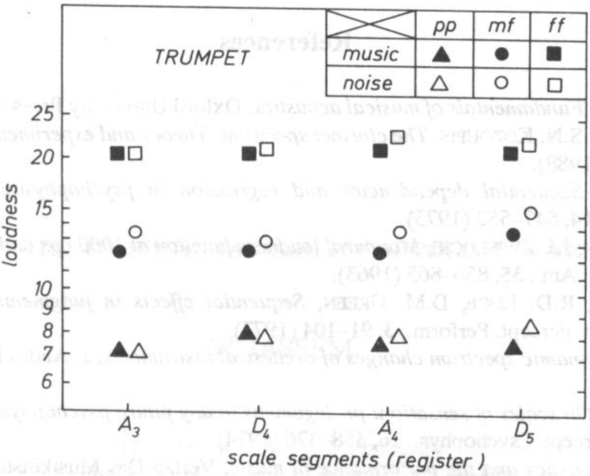


Fig. 9. Loudness of musical passages played on a trumpet and loudness of corresponding wide-band noise signals. Geometric means of 30 estimates.

sounds having different spectral structure differ in other subjective attributes. As a result, subjects' responses may be biased by other perceptual dimensions [12].

4. Conclusions

The results show that loudness estimates of music and noise agree reasonably well. This finding suggests that the principles of loudness judgment derived from non-musical stimuli also apply to the tones of musical instruments. In some cases the discrepancies between loudness estimates of music and noise are greater. This appears to depend on spectral structure. Further investigation is required to explain such differences.

The general convergence of loudness estimates of musical and noise stimuli demonstrates that methods used for noise measurements may give a reasonable approximation of loudness in music. However it should be kept in mind that the musical stimuli in the present study were not longer than a few seconds. Experiments with more complex musical stimuli will be necessary before a general conclusion can be drawn.

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