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ABSTRACT

The absolute semitone scale is a scale combining the properties of both physical and perceptual units. It is derived from a modified Fletcher's formula,

 $P(st) = 12 \log_2 F_0(Hz),$

to relate fundamental frequency to its correlate perceptual units of pitch, viz., semitones above 1 Hz (1 Hz = 0 st). The absolute pitch units are much more convenient than Hz for the presentation. comparison (i.e., calculation of relative pitch differences) and other processing of raw data obtained in instrumental prosodic research.

In prosodic research the presentation of fundamental frequency in cycles per second is admissible only as far as raw measurement data are concerned. Any further manipulation and discussion or interpretation of the data should be carried out in units of perception. Even the graphs of F movement applying the linear frequency scale are perceptually misleading: they give a wrong idea of an extensive pitch movement which is never perceived by listeners as such. The logarithmic scale is a solution for graphs, although not very convenient for plotting unless one has special charts where every cps (Hz) can be plotted accurately.

The comparison and statistical processing of raw data in Hz in terms of perception leads to distortions even in case of one speaker, let alone speakers with different F ranges. The perceptually relevant comparison of two tones can be carried out by calculating their ratio, which further may be converted into semitones. Thus, given two measured frequencies, 150 Hz and 100 Hz, it is useless to state, in a discussion of their perception, that their difference is 50 Hz: the perception of the 50 Hz difference here is quite unlike the perception of a 50 Hz difference, say, between 250 Hz and 200 Hz. Instead, one can state that the ratio of the first pair of frequencies is 3:2 whereas that of the second pair is 5:4. For an untrained imagination, however, it is still clearer to state that the (musical) interv a l between the first two frequencies is 7 semitones, or a fifth, and that between the other two frequencies is 4 semitones, or a third.

But calculating average F values in Hz is of very doubtful value, as is drawing conclusions from differences between such values or such averages. To say that one F_0 contour individually or on an average differs from another by a 10 Hz difference between their peaks is guite meaningless.

As long as we believe that the perception of the fundamental frequency of speech is logarithmic in the same way as it is for pure tones, the only possibility to pro-cess F data mathematically is in linear units on the logarithmic scale to which the data should be converted. The basic unit of pitch is the octave. The convenient unit for the analysis of fundamental pitch is the semitone. Proceeding from FLETCHER (1929) who introduced a scale of octaves and centioctaves above 1 kHz for the whole of the audible pitch range, it is possible to modify Fletcher's formula for calculating the pitch of the voice fundamental in a b s o l u t e s e m i-

to n e s a b o v e 1 Hz : P (st) = 12 log₂ F_0 (Hz \approx cps). According to this formula, 1 Hz = 0 st, 2 Hz = 12 st, 4 Hz = 24 st, 64 Hz = 72 st, 512 Hz = 108 st (Fig. 1). That is, instead of operating with figures in the F range of (roughly) 64..512 Hz, we can operate in the pitch range of 72.. .. 108 st. The figures of the latter scale are suited for any kind of mathematical processing without notably violating the perceptual reality. Considering these two pairs of numerical data (depicted in Fig. 2), we can easily find the average pitch of the latter pair to be 90 st; the difference (interval) between the lower pitch and the average as well as between the higher pitch and the average is 18 st (1.5 octaves). The result is perceptually informative, unlike the average of the two former figures, 288 Hz, where the lower interval would be about 26 st as against 10 st of the upper interval.

Data in Hz can easily be converted into absolute semitones by means of a table where every Hz is given its correlate



Fig. 1. (Left.) Linear frequency scale in Hertz (left) and the correlate pitch values in semitones (right).

Fig. 2. (Right.) Linear pitch scale in st (left) and the correlate frequency values in Hz (right). Plotting of two fundamental frequencies, $F_1 = 64$ Hz and $F_2 = 512$ Hz, on the linear pitch scale and the correlate logarithmic frequency scale. F is the mean frequency, P is the mean pitch of the two signals.

value in st with the accuracy of .1 st (higher precision is unnecessary in phonetics). This table is printed on the 4th page of the present paper. In computerassisted F extraction the conversion can be done automatically, applying the above formula. For a programming language applying natural logarithms (such as BASIC used for computing the given conversion table) the formula will be

 $P = 12 \times 1.442695 \times \ln F$. It would be highly advisable to present even raw data in these absolute perceptual units. The investigator himself could immediately estimate the perceivable differences between the measured parameters of pitch and carry out all kinds of mathematical operations with the data without the ad hoc calculation of ratios or finding of logarithms. Intervals could be calculated by simple subtraction. Pitch contours and other graphs can easily be drawn on ordinary square paper.

The reader, too, could at once see what the measured pitches, intervals and ranges mean in terms of perception. Also, a reader of publications applying the absolute semitone scale could easily compare the data of different authors without the need to convert the Hz into ratios and then back into the traditional but unnecessary Hz if he wants to publish his results of comparison. One could combine and process the results and initial data for further generalizations, compute averages of pitch contours of different authors (including one's own), etc.

For example, the paper of LIN et al. (1984) includes two tables representing the average pitch in 2- and 3-syllable tone groups of Chinese. Pitch is expressed in Hz. Let us consider a line of their Table 1 - tone 4 + tone 3:

1st syll. 2nd syll. 196-110 male speaker 104-82-114 female speaker 242-152 143-82-156 The figures are given as averages. Although it is wrong in phonetics to average hertzes (what can be averaged is their logarithms), let us regard these figures as representing single speech acts. All we can see is that both speakers pronounce the first syllable with falling pitch and the second with a fall-rise which is steeper for the female speaker. Now let us convert the hertzes into semitones:

1st syll. 2nd syll. 91.4-81.4 80.4-76.3-82.0 male speaker female speaker 95.0-87.0 85.9-76.3-87.4 Here the extent of pitch movement is at once obvious: the male speaker appears to make a 10-st fall in the 1st syllable against the female speaker's 8 st; the 2nd syllable starts 1 st below the end of the 1st; the subsequent falls in the 2nd syllable are 4 st and nearly 10 st, respectively, and the final rises about 6 and 11 st, respectively. Further comparison with the other tone groups in the table

may show to what extent these findings are relevant.

Another aspect. In order to average the two pitch contours of the above tone group, with their parameters expressed in Hz, we would have to draw both of them on logarithmic paper and calculate the average contour geometrically (Fig. 3). Yet it is much simpler to average the parameters expressed in st arithmetically.

(m+f)/2 93.2-84.2 83.2-76.3-84.7, and draw the resulting contour of the same shape on square paper.



- Fig. 3. Plotting and averaging of two contours of a Chinese tone group on the logarithmic frequency scale and absolute semitone scale.
- male speaker
- ----- female speaker
- -.-.. the average contour

When synthetic speech is used in prosodic research, it is expedient, with a view to their subsequent mathematical/statistical analysis, to make up the tonal contours for the synthetic stimuli in absolute pitch units, varying the pitch of certain contour points by steps of m st instead of n Hz. It will considerably facilitate, for instance, correlation analysis between the input pitch data and the listeners' responses when the former are expressed in semitones on the absolute linear pitch scale; and it is equally easy to interpret the results of such analysis.

The absolute semitone scale was first introduced in Tallinn in 1972 (VENDE 1972) and has since been successfully applied here (e.g., PIIR 1985).

The other existing pitch scales, such as the mel scale or the Bark scale, are efficient for plotting psychoacoustic data for frequencies above 500 Hz, i.e. for spectrum analysis, but apparently not sensitive enough and too clumsy to handle (otherwise why should prosodists have avoided them?) in the range of fundamental frequency. It remains to hope that the absolute semitone scale, which is likewise both physical and perceptual, will gradually break through the hitherto dominating hertz tradition, take root and spread in prosodic research.

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TABLE

Conversion of Hertzes into Semitones

Hz st Hz st Hz st Hz st Hz st 244 95.2 313 99.5 382 1 0.0 60 70.9 91.9 62.7 178 09.7 247 95.4 316 99.6 384 1 15.0 62.7 171.2 120 82.0 100 99.9 249 95.5 317 99.7 386 319.9 98.9 385 21.0 63 72.1 122 83.2 101.0 121.0 123.0 121.0 125.0 72.1 123.0 125 95.7 72.1 99.9 386 67 72.1 123.0 126 83.7 125.0 125.0 123.0 125 95.7 72.0 99.9 37.3 126 84.0 136 90.3 255 95.9 72.2 180.0 332 139.9 63 66 72.8 126 83.7 127 180.2 386 121 180.1 332 180.1 333 180.5 131.0 130.1 133.1 1										2	242	95.0	311	99.4	380	102.8	449	105.7
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$		26	56.4	85	76.9	144	80.0	203	92.1		273	97.1	342	101.0	411	104.2	480	106.9
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		27	57.1	86	77.1	145	86.2	204	02 2		274	97.2	343	101.1	412	104.2	481	106.9
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	28	57.7	87	77.3	146	86.3	200	26.6		275	97.2	344	101.1	413	104.3	482	107.0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		29	58.3	88	77.5	147	86.4	205	24.4		276	97.3	345	101.2	414	104.3	483	107.0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		30	58.9	89	77.7	143	86.5	207	72.3		210	97 4	346	101.2	415	104.4	484	107.0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	ĺ	31	59.5	90	77.9	149	86.6	208	92.4		211	07 4	747	101.3	416	104.4	485	107.1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		32	60.0	91	78.1	150	86.7	209	92.5		210	07 5	748	101.3	417	104.4	486	107.1
34 61.0 93 78.5 152 87.0 211 92.7 280 97.6 350 101.4 413 35 61.6 94 78.7 153 87.1 212 92.7 281 97.6 350 101.4 413 36 62.0 95 78.8 154 87.2 213 92.8 282 97.7 351 101.5 422 37 62.5 96 79.0 155 87.3 214 92.9 233 97.7 352 101.6 422 38 63.0 97 79.2 156 87.4 215 93.0 284 97.9 355 101.6 422 40 63.9 99 79.4 157 87.5 216 93.1 286 97.9 355 101.7 424 44 64.3 100 79.7 159 87.6 217 93.1 286 97.9 355 101.7 424 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 422 41 64.3 100 79.7 159 87.8 219 93.3 299 98.1 358 101.8 422 42 65.1 102 80.1 161 88.0 220 93.4 299 98.1 358 101.9 422 44 65.5 103 80.2 162 <td></td> <td>33</td> <td>60.5</td> <td>92</td> <td>78.3</td> <td>151</td> <td>86.9</td> <td>210</td> <td>92.6</td> <td></td> <td>279</td> <td>97.5</td> <td>2/9</td> <td>101.4</td> <td>418</td> <td>104.5</td> <td>487</td> <td>107.1</td>		33	60.5	92	78.3	151	86.9	210	92.6		279	97.5	2/9	101.4	418	104.5	487	107.1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		34	61.0	93	78.5	152	87.0	211	92.7	i	280	97.0	242	404 4	419	104.5	488	107.2
36 62.0 95 78.8 154 87.2 213 92.8 282 97.7 351 161.5 422 37 62.5 96 79.0 155 87.3 214 92.9 283 97.7 352 101.6 422 38 63.0 97 79.2 156 87.4 215 93.0 284 97.9 354 101.6 422 40 63.9 99 79.4 157 87.5 216 93.1 286 97.9 355 101.7 424 41 64.3 100 79.7 159 87.8 218 93.2 287 98.0 355 101.7 424 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 422 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 422 43 65.1 102 80.2 162 88.1 221 93.5 290 98.2 359 101.9 423 44 65.5 104 80.4 163 88.2 222 93.5 291 98.2 360 101.9 423 44 65.9 104 80.4 163 88.2 222 93.5 291 98.3 362 102.0 433 45 66.7 106 80.7 165 <		35	61.6	94	78.7	153	87.1	212	92.7		281	97.6	200	404 5	420	104.6	489	107.2
37 62.5 96 79.0 155 87.3 214 92.9 283 97.7 352 101.6 422 38 63.0 97 79.2 156 87.4 215 93.0 284 97.8 353 101.6 422 39 63.4 98 79.4 157 87.5 216 93.1 285 97.9 354 101.6 422 40 63.9 99 79.6 158 87.6 217 93.1 286 97.9 355 101.7 424 41 64.3 100 79.7 159 87.8 218 93.2 287 98.0 356 101.7 424 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 422 43 65.1 102 80.1 161 88.0 220 93.4 299 98.1 358 101.9 423 44 65.5 103 80.2 162 88.1 221 93.5 291 98.2 360 101.9 423 44 65.5 104 80.4 163 88.2 222 93.5 291 98.3 362 102.0 433 45 67.7 106 80.7 165 88.4 224 93.7 293 98.5 364 102.0 433 47 66.7 107 80.9 166 <		36	62.0	95	78.8	154	87.2	213	92.8	i	282	97.7	301	101.5	421	104.6	490	107.2
38 63.0 9779.2156 87.4 215 93.0 234 97.8 353 101.6 421 39 63.4 9879.4 157 87.5 216 93.1 285 97.9 355 101.7 424 40 63.9 9979.6 158 87.6 217 93.1 286 97.9 355 101.7 424 41 64.3 100 79.7 159 87.8 218 93.2 287 98.0 356 101.7 424 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 421 43 65.1 102 80.1 161 88.0 220 93.4 289 98.1 358 101.9 422 44 65.5 103 80.2 162 88.1 221 93.5 291 98.2 360 101.9 422 45 65.9 104 80.4 163 88.2 222 93.5 291 98.2 361 102.0 433 46 66.3 105 80.6 164 88.3 223 93.6 294 98.4 363 102.0 433 47 66.7 106 80.7 165 88.4 224 93.7 293 98.5 365 102.0 433 48 67.4 108 81.1 167 88.6 226		37	62.5	96	79.Ø	155	87.3	214	92.9	i	283	97.7	302	404 6	422	104.7	491	107.3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		38	67 0	97	79.2	156	87.4	215	93.0	i	284	97.8	202	101.0	477	104.7	492	107.3
40 63.9 99 79.6 158 87.6 217 93.1 286 97.9 355 101.7 42.7 41 64.3 100 79.7 159 87.8 218 93.2 287 98.0 356 101.7 42.7 42 64.7 101 79.9 160 87.9 219 93.3 288 98.0 357 101.8 42.7 43 65.1 102 80.1 161 88.0 220 93.4 289 98.1 358 101.8 42.7 44 65.5 103 80.2 162 88.1 221 93.5 290 98.2 359 101.9 42.7 44 65.5 103 80.2 163 88.2 222 93.5 291 98.2 360 101.9 42.7 45 65.9 104 80.4 163 88.2 222 93.5 291 98.2 360 101.9 42.7 45 65.7 106 80.7 165 88.4 224 93.7 293 98.3 361 102.0 43.7 47 66.7 1007 80.9 166 88.5 225 93.8 295 98.5 364 102.1 43.7 49 67.4 108 81.1 167 88.6 226 93.8 295 98.5 364 102.1 43.7 49 67.4 108 81.1 <		20	67 4	00	70 4	157	87.5	216	93.1		285	97.9	304	101.0	404	104 7	497	107.3
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		40	67 0	20	70 4	459	87.6	217	93.1	:	286	97.9	300	101.7	42.4	104.1	494	107.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	44	64 7	27	70.7	459	87.8	218	93.2	;	287	98.0	356	101.7	420	104.0	495	107.4
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	ł	42	04.3	100	77.1	102	07 9	219	93.3		288	98.0	357	101.8	420	104.0	106	107.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		47	04.7	101	(3.3	100	00 0	220	93.4		289	98.1	358	101.8	421	104.9	497	107.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	Í	43	65.1	102	80.1	161	00.0	221	93.5		290	98.2	359	101.9	428	104.9	100	107 5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		44	65.5	103	80.2	162	00.1	222	97.5		291	98.2	360	101.9	429	104.9	400	107.6
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	•	45	65.9	104	80.4	163	88.2	007	97.6		292	98.3	361	102.0	430	105.0	477	107.5
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		46	66.3	105	80.6	164	88.3	223	07.7		293	98.3	362	102.0	431	105.0	500	107.0
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		47	66.7	106	80.7	165	88.4	224	07 0		294	98.4	363	102.0	432	105.1	501	107.6
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		48	67.0	107	80.9	166	88.5	223	07 0		295	98.5	364	102.1	433	105.1	502	107.7
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		49	67.4	108	81.1	167	88.6	226	73.0		296	98.5	365	102.1	434	105.1	503	107.7
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		50	67.7	109	81.2	168	88.7	227	93.9		220	98.6	366	102.2	435	105.2	504	107.7
52 68.4 111 81.5 170 88.9 229 94.1 276 98.7 368 102.3 43 53 68.7 112 81.7 171 89.0 230 94.1 299 98.7 368 102.3 43 54 69.1 113 81.8 172 89.1 231 94.2 300 98.7 369 102.3 43 55 69.4 114 82.0 173 89.2 232 94.3 301 98.8 370 102.4 43 56 69.4 114 82.0 173 89.2 232 94.4 302 98.9 371 102.4 44 56 69.7 115 82.1 174 89.3 234 94.4 303 98.9 372 102.5 44 57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 373 102.5 44 58 70.3 117 82.4 176 89.5 23		51	68,1	110	81.4	169	88.8	228	94.0		-21 200	98.6	367	102.2	436	105.2	505	107.8
53 68.7 112 81.7 171 89.0 230 94.1 299 56.7 360 102.3 43 54 69.1 113 81.8 172 89.1 231 94.2 300 98.7 369 102.3 43 55 69.4 114 82.0 173 89.2 232 94.3 301 98.8 370 102.4 43 56 69.4 114 82.0 173 89.2 232 94.4 302 98.9 371 102.4 44 56 69.7 115 82.1 174 89.3 233 94.4 303 98.9 372 102.5 44 57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.0 116 82.3 175 89.4 235 94.5 304 99.0 373 102.5 44 59 70.6 118 82.6 177 89.6 23		52	68.4	111	81.5	170	88.9	229	94.1		220	00.7	368	102.3	437	105.3	506	107.8
54 69.1 113 81.8 172 89.1 231 94.2 300 98.7 369 102.3 43 55 69.4 114 82.0 173 89.2 232 94.3 301 98.8 370 102.4 43 56 69.7 115 82.1 174 89.3 233 94.4 302 98.9 371 102.4 44 57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.3 117 82.4 176 89.5 235 94.5 304 99.0 373 102.5 44 59 70.6 118 82.6 177 89.6 236 94.6 305 99.0 374 102.6 44	ł	53	68.7	112	81.7	171	89.0	230	94.1		233	20.1 00 7	720	102.7	438	105.3	507	107.8
55 69.4 114 82.0 173 89.2 232 94.3 301 98.8 370 102.4 44 56 69.7 115 82.1 174 89.3 233 94.4 302 98.9 371 102.4 44 57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.3 117 82.4 176 89.5 235 94.5 304 99.0 373 102.5 44 59 70.6 118 82.6 177 89.6 236 94.6 305 99.0 374 102.6 44		54	69.1	117	81 8	172	89.1	231	94.2		300	98.(00 C	202	102 4	479	105.3	508	107.9
56 69.7 117 82.0 174 89.3 233 94.4 302 98.9 371 102.4 44 56 69.7 115 82.1 174 89.3 233 94.4 303 98.9 372 102.5 44 57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.0 116 82.3 175 89.4 235 94.5 304 99.0 373 102.5 44 58 70.3 117 82.4 176 89.5 235 94.5 304 99.0 374 102.5 44 59 70.6 118 82.6 177 89.6 236 94.6 305 99.0 374 102.6 44	1.	55	C0 4	114	82 Ø	177	89.2	232	94.3		301	98.8	 ≁	402 4	440	105.4	509	107.9
57 70.0 116 82.3 175 89.4 234 94.4 303 98.9 372 102.5 44 58 70.3 117 82.4 176 89.5 235 94.5 304 99.0 373 102.5 44 59 70.6 118 82.6 177 89.6 236 94.6 305 99.0 374 102.6 44		56	20 7	445	02.0	174	89.3	233	94.4		302	98.9	172	402 5	440	105.4	510	107.9
58 70.3 117 82.4 176 89.5 235 94.5 304 99.0 373 102.5 44 59 70.6 118 82.6 177 89.6 236 94.6 305 99.0 374 102.6 44		50	70-0	110	04.1	475	89.4	234	94.4		303	98.9	372	102.0		100.7	544	108.0
59 70.6 118 82.6 177 29.6 236 94.6 305 99.0 374 102.6 44		50	70.0	115	02.J	470	00 5	235	94.5		304	99.0	373	102.5	442	405 E	843	108.0
JZ 70.6 118 82.6 177 52.9 500 500 500		50	10.5	11/	o∠.+	710	00.0	236	94.6		305	99.0	374	102.6	443	Te0.0	916	
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