An Analysis of Tone Durations in Recorded Musical Performances

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Abstract

The effect of pitch on tone durations was studied in several pieces of music. In previous work it was found that higher pitched sounds, of a given duration, were perceived to be of longer duration. That work, however, was not undertaken in a musical context. The present work was done to determine whether the previously observed trend was also apparent in musical performances. Several measurements were undertaken One of these involved analysing the recorded performance duration of notes in several performances of the Mozart Flute Quartet in A-major, K.298. Performed durations were also obtained from a Bach Flute Sonata and a Brahms Clarinet Quintet. An analysis of the musical performances revealed that while there were individual differences and exceptions in notes, the musicians tended to play higher notes significantly shortened.

I. Introduction

Whenever skilled musicians play alone or in an ensemble, they play with expression. To be expressive musicians use modifications of timing, dynamic, articulation and other expressive parameters (e.g., subjective duration, rhythm, timbre, roughness, pitch, harmony). Many researchers [1-3] have found that a performer's introduction of expression is not based on a number of fixed expressed patterns that the performer has learned, but is more closely related to musical structure. However, some empirical investigations [4-6] of timing in performance, especially with regard to deviations from mechanical regularity in different types of music and with different performers, have shown that it is rarely understood how extreme and varying the deviations of tone durations really are. Other research on music performance involving duration measurement has revealed the performers' precise internal representation of underlying expressive form [2] and the performers' use of lengthening in the phrase finals [7].

The performers are also listeners. They continuously check that there is a correspondence between their intentions and the music they produce. Music sounds unacceptable when performed by a digital computer in agreement with what is written in the music score. Deviations from the score constitute an essential part of music communication. As Sundberg [8] has argued, these deviations or doscrepancies are not random and must be meaningful, that is, they must carry information that the listener needs to enjoy the performance. What is this information? How is the mucsical code chosen when used by the musician for conveying it? Is this code used in music only or is part of it borrowed from extramusical communication? Seashore [9] found that *tempo rubato* depends upon the ability to hear and to produce fine temporal shadings in order to produce the desired modulation. It seems a reasonable hypothesis that variations in the tone durations may contribute to the musicality of performances.

This work investigates whether the tone duration depends on the pitch of the tones, *i.e.*, whether there is a link between the results of the previous research [10-12] and music performances. In their work, the effect of frequency on duration perception was revealed both by comparing the proportion of correct responses and by calculating the duration difference limens of the subjects. For different frequency sound pairs, subjects perceive the higher frequency sound to be longer in duration. When one tone in a pair has a different frequency from the other (both tones were in the range 0.25 to 4 kHz), it was found that the higher frequency tends to be judged longer in duration. The effect of frequency difference on duration is likely to be reflected in musicians' performances of music, but so far it has been unclear whether the perceptual data apply to musical tone durations. Several experiments were motivated by an interest in the range of applicability of the temporal psychoacoustical data to the complex contexts of mixed sequences in music. The hypothesis in the present study is that higher pitched tones

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will be played shorter than lower pitched tones, of the same nominal note value, in musical performances. Although it is not clear that the higher-shorter effect is any way causally related to timing in expressive musical performance, awareness of the effect is important if expression is to be studied without the higher-shorter effect confounding observations.

Ⅱ. Measurements

The tone durations in some recorded music were measured. Two different pieces of flute music were first compared in terms of tone durations of performances. Then a further investigation was undertaken to find the effect of frequency on the tone durations in other recordings. The music and performances were chosen because they were familiar and available. The flute and clarinet produce individual waveforms that allow easy determination of the duration of each tone.

For most of the experiments described in this work the performances were stored as sound files on a computer. Any part of the performance could be extracted for detailed listening and analysis of transitions between tones, for spectral analysis, etc. They were analysed using SoundEdit software, which simultaneously displays the variations of total amplitude (intensity) and frequency or lapse of time (duration). Band-pass filtering and calibrations made it possible to get very accurate representations of monophonic performances and in many cases also of polyphonic music. Once the performance was recorded as a sound file, it was subdivided according to the time signature and the length of the file.

The individual tone durations were measured from time-amplitude displays of filtered music. The word "duration" is defined, for the purpose of this paper, as the time interval between onset of one note and the onset of the next. Thus the total duration of one tone includes the off-time duration, as found in the case of staccato notes. Where any trace of sound discontinuity was not available, either because of weak sounds or sounds with a gradual increase in amplitude, the experimenter's audible amplitude point in the sound envelope was taken as the tone onset. Final notes, notes in an incomplete bar, and notes followed by a rest were omitted, since their tone durations could not be measured accurately. Each tone duration was measured with an accuracy of ±5 msec [6].

Despite the accuracy of the computerized equipment there are still problems in determining tone durations in certain cases, especially regarding physical and perceptual tone onsets. The registered acoustical events are often complex. For example, two tones which, by the score, should come sequentially, overlap each other. Because of these factors the determination of tone durations was carried out by a musician having 15 years of musical experience, who had absolute pitch and obtained low just noticeable differences (JNDs) in sound duration tests [11].

Performers & Music

The performances of four contemporary flutists, Baron, Blau, Schulz and Beaucoudray, were analysed and compared by measuring tone durations (the flute part only). The first three artists' recordings of the Mozart Flute Quartet in A-major, K.298 and the Beaucoudray's recording of the Bach Flute Sonata in E-minor were analysed (See Section 2.3.). Samuel Baron's performance of the Mozart was randomly selected and further analysed as a tone duration test for the full music performance. Finally, Jost Michaels' performance of the Brahms Clarinet Quintet in B-minor was analysed in order to determine whether the results obtained for the flute works were instrument specific.

Measurements of Tone Durations

As shown in Fig. 1, the tone durations can be visually differentiated by the distinctive appearance in the waveform (amplitude variation). The difference in dynamics of music also seems to change waveforms. In Fig. 1(a), Baron's performance of the first repeated part of *VAR. I* (the Mozart Quartet) was measured (the durations of the first six tones were 575, 305, 181, 408, 293, 285 msec respectively). The first note (575 msec) was a quarter-note but it was not included in the tone duration analysis as it was in an incomplete bar. The other notes are eighth-notes. As shown in Fig. 1(b), the discontinuity becomes clear when the visual image of the tones is horizontally extended, *i.e.* 'zoomed in'. The durations of the two tones shown are 508 and 582 msec. As shown in Fig. 1(c), transient or transitional sounds which obscure the onset of the following note are sometimes found. This is a rare occurrence and has a short duration. In the worst case the duration of the transient part was less than 7 msec so that the mean square error of duration assessment is still within ±5 msec.

Procedure

The notes used for analysis were those that were performed at least twice in a given section of the pieces chosen. For the Quartet (first 15 repeated bars of the

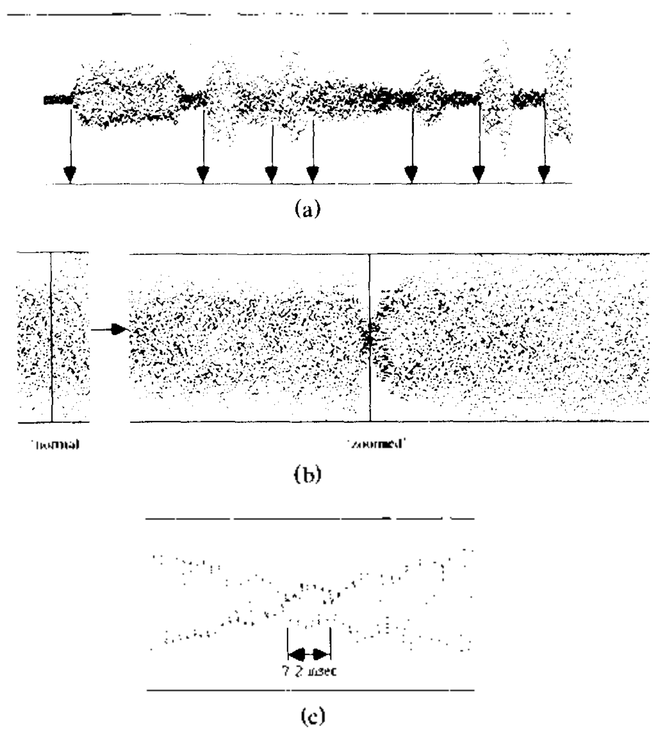

Figure 1. Three visual examples of the tone duration determination : (a) Discontinuity-the onset points of the first, second, etc notes are indicated. (b) Determination of onset of tones using the zoom function. (c) Example of the overlapping of tones in the performances.

Andante), the quarter-notes were selected as they are the most common durations. The performance durations of sixteenth-notes were measured in the Bach sonata (first 29 bars in *Adagio ma non tanto*). The duration-measured notes were E4, F#4, G#4, A4, A#4, B4, C#5, D5, D#5, E5, F#5, G#5 and A5 (13 notes) for the Mozart, and E4, F#4, G4, A4, A#4, B4, C5, C#5, D5, D#5, E5, F#5, G5, A5 and B5 (15 notes) for the Bach.

Each measurement of the tone duration was normalized as a proportion of the performance duration of the bar to which the quarter-note or the sixteenth-note belonged. For a comparison of tone durations in different parts of the music and for using data from different performances, this normalization is required because the tempo and time signature of the music may vary.

Baron's performance of the Mozart Quartet was further studied by measuring the tone durations throughout the work. The range of measurements was extended to include eighth-notes, quarter-notes and dotted quarter-notes in three different time signatures (4/4, 3/4 and 2/4). The performance durations of quarter-notes, dotted quarter-notes and eighth-notes were selected and measured in the 4/4 parts (*THEMA, VAR. I-IV*). Quarter-notes and eighth-notes were used in the analysis in the 3/4 part (*MINUETTE*). In the 2/4 part (*RONDEAU*), eighth-notes were the only notes available in any significant number, and were selected for analysis.

The recording of the Brahms Clarinet Quintet in B-minor was analysed by measuring tone durations (the clarinet part only). The performance durations of eighth-notes were selected and measured in the 6/8 parts (*Part I*) of the Quintet, while quarter-notes, dotted quarter-notes and eighth-notes were used in the analysis in the 3/4 part (*Part II*). In the 4/4 part (*Part III*) quarter-notes and eighth-notes were used. The rest of the Quintet (the 2/4 part, *Part IV*) was not analysed as the part has a fast tempo (*con moto*) and the tone durations of its dominant notes (sixteenth-notes) are too short. Tone durations were averaged at each frequency and plotted as a function of frequency.

III. Results

The normalized duration for each note performed was averaged and this was plotted in Fig. 2, as a function of frequency. The relation between the mean performance durations of quarter-notes in the Mozart Flute Quartet and the frequency of the tones is shown in Figs. 2(a)-(c) and had Spearman rank correlation coefficients $r_s = -.55$, .56 and $-.53$ ($p = .06$, .05 and .06 — paired two group test) for the Baron, Blau and Schulz performances, respectively. In the analysis of the Beaucoudray's performance of the Bach Flute Sonata, as shown in Fig. 2(d), no significant dependence of tone durations on frequency was found [$r_s = -.31$, $p = .25$]. Although the significance level is not very great, Fig. 2 shows broadly that the musicians performed the higher tones with shorter durations.

Mean values of performed durations of tones in the Mozart Flute Quartet in A-major, K.298, performed by Baron, are presented as a function of frequency in Fig. 3. The purpose of this further investigation was to determine whether the average tone durations, other than quarter-notes, had the same trend as that shown in Fig. 2. In the 4/4 time signature, it can be seen that Baron performed the higher pitched tones with shorter duration. It was found that the correlation, r_s, between the performed durations of the quarter-notes and the frequency of tones was $-.79$. A value as large as this is significant at the $p < .01$ level. For dotted quarter-notes $r_s = -.67$ with $p = .08$, and for eighth-notes $r_s = -.45$ with $p = .14$. In the Mozart performance analysed, the quarter-note was the predominant note value. Similar trends were not found for the other

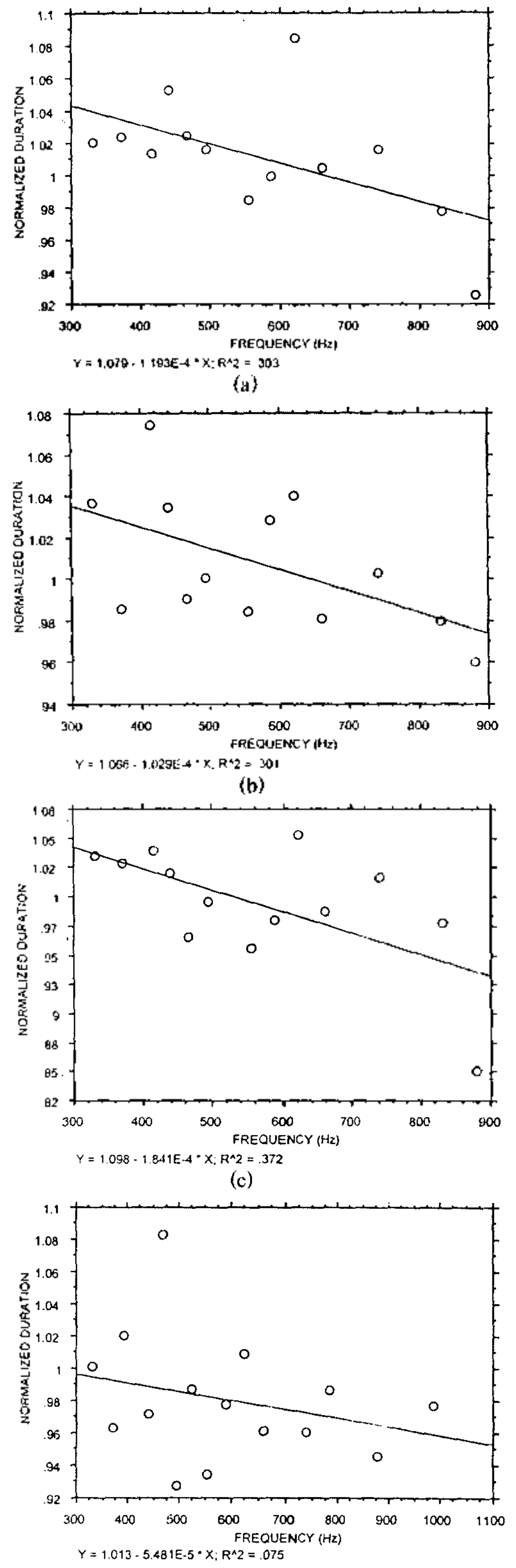

Figure 2. Comparison of the normalized tone durations obtained from three performances (Baron (a), Blau (b) and Schulz (c)) of the Mozart Flute Quartet in A-major, K.298 and Beaucoudray's (d) recording of the Bach Flute Sonata in E-minor. The mean normalized duration/standard deviation of the tones analysed in the four performances are 1.01/0.04, 1.01/0.03, 0.99/0.05 and 0.98/0.04, respectively.

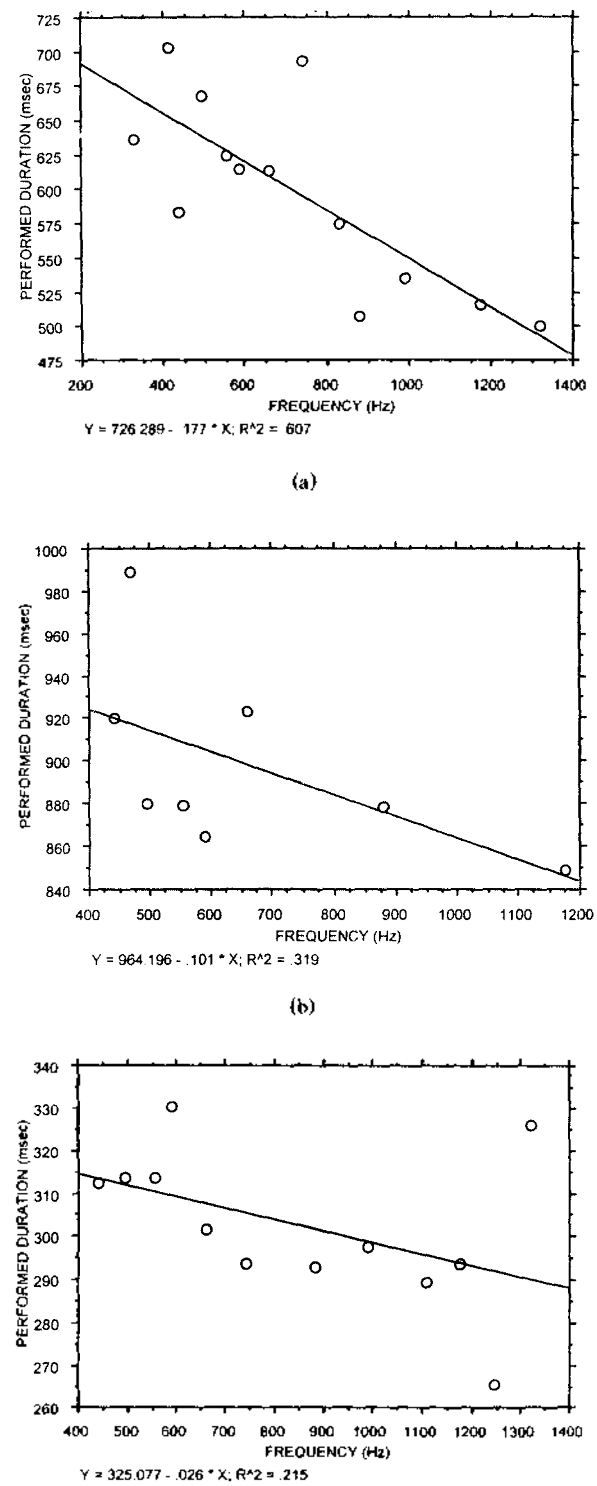

Figure 3. Mean values of performed durations in sections of the Mozart Flute Quartet in A-major, K.298 with the 4/4 time signature (*Thema, Var. I, II, III and IV*), as a function of frequency (Hz): Quarter-notes (a), Dotted quarter-notes (b), and Eighth-notes (c). The mean duration (msec)/standard deviation (msec) of the tones analysed for the Quarter-notes, Dotted quarter-notes, and Eighth-notes are 598/69, 898/45, and 303/18, respectively.

time signatures, *i.e.*, the 3/4 (Menuetto) and 2/4 (Rondeau) sections, where the predominant note values are eighth-notes.

Mean values of tone durations in the Brahms Clarinet Quintet in B-minor are shown as a function of frequency in Fig. 4. The purpose of this experiment was not only to provide further evidence of dependency of tone durations on pitch but also to check whether the relationship shown in Figs. 2 and 3 is instrument specific. The results can be seen in Fig. 4. The performed durations of the eighth-notes, both in 6/8 [$r_s = -.70$, $p < .01$] and 4/4 [$r_s = .72$, $p < .01$], show that Michaels performed the higher tones with shorter durations, as found in the performances of the Mozart. In the parts of the performance analysed, the eighth-note was the most prevalent note value. For the quarter-notes in the 4/4 part (*Part III*) the above trend was not found ($r_s = -.22$ with $p = .42$). The trend was not found either for other note values or for the 3/4 time signature.

All time signatures and note values from the performances of the Mozart Flute Quartet in A-major, K.298 and the Brahms Clarinet Quintet in B-minor were included for further analysis. Each measurement of a given tone was normalized as a proportion of the mean performance duration of all tones, of that note value, in the section in which the note was performed, *i.e.*, quarter-notes were normalized by the average length of quarter-notes and eighth-notes by the average length of eighth-notes in a particular movement of the music. Mean values of the normalized tone durations obtained from the two perfor-

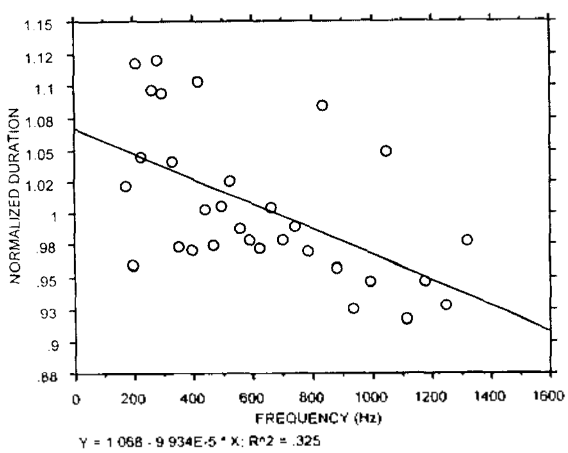

Figure 5. Mean values of the normalized tone durations obtained from the performances of the Mozart Flute Quartet in A-major, K.298 and the Brahms Clarinet Quintet in B-minor, as a function of frequency (Hz). All time signatures and note values are included in this analysis.

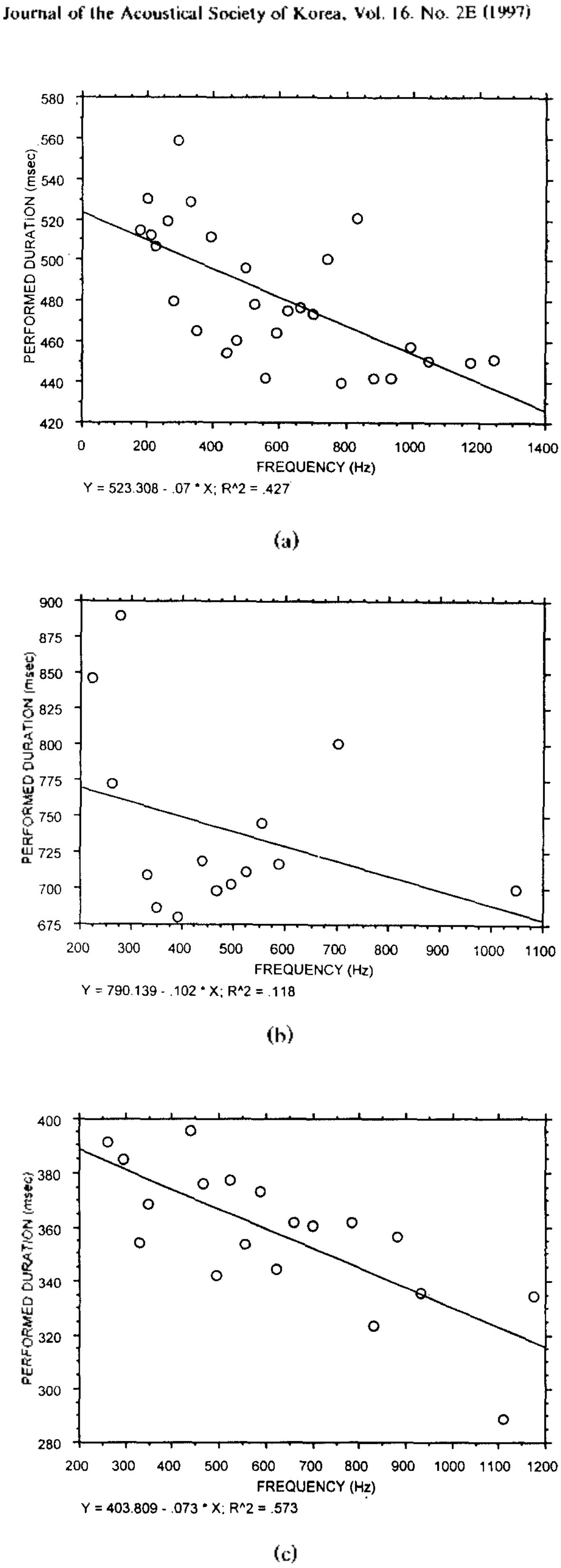

Figure 4. Mean values of performed durations of eighth-notes (a) in *Part I* (6/8), and Quarter-notes (b) and Eighth-notes (c) in *Part III* (4/4) of the Brahms Clarinet Quintet in B-minor, as a function of frequency (Hz). The mean duration (msec)/standard deviation (msec) of the tones analysed are 483/33, 742/63, and 358/26 from the top.

mances are shown as a function of frequency in Fig. 5. The variation of performed durations of tones is significant [$r_s = -.57$, $p < .01$]. Four time signatures (2/4, 3/4, 4/4 and 6/8) and four note values (eighth-note, sixteenth-note, quarter-note and dotted quarter-note) were included in the overall analysis of variation in the tone durations. In all the parts of the performances analysed the eighth-note and quarter-note were the most prevalent note values. The notes which appeared in only one section, through the performances, were excluded from the analysis. There were three such notes (F#3, F#4 and F#6).

Ⅳ. Discussion and Conclusions

The effect of frequency on the tone durations was studied in several pieces of music and it was found that an octave change in pitch could make a difference of up to 20% in the length of the performed tones. It is concluded that the performed length of notes in music not only depends on musical expression (used by the performer) but also depends on the pitch in many instances. In comparing the two different pieces of flute music, a larger variation in performances was found in the Bach than in the Mozart. As shown in Fig. 2, the normalized durations of the sixteenth-notes in the Bach piece were mostly below '1', whereas, the normalized durations of the quarter-notes in the Mozart piece were evenly spread around '1'. This may be because significant changes in music expression are led by the flute in the Sonata, which could be interpreted as the musician trying to make the music less 'mechanical'. In such sonatas and in the Bach, it is the flutist or the pianist who varies the expressive parameters [3] when they are in the leading part of the sonata. In addition, the expressive variables such as intensity and vibrato are interdependent within the musical structure. There may be variation among different performers' interpretations of a musical work and intra-individual variations as well. However, from the Mozart results, the trend was the same for the three performers and so it can be concluded that the dependency of duration on frequency is not performer specific.

The trend of the dependence of tone duration on frequency is not statistically significant in all sections of the music analysed. For the quarter-notes in the 4/4 time signature of the Mozart Flute Quartet, and the eighth-notes in the 6/8 and 4/4 time signature of the Brahms Clarinet Quintet (where one note value dominates in a section), a clear trend of the effect of frequency on tone durations was found. The performances of the tone durations are mainly dependent on pitch but in sections of mixed note values, other factors (e.g., dynamics, rhythm, harmony, etc.) may well be more important for the performers' musical expression. A few other notes which appear to be less and to have greater variations in tone durations were checked, but variations from the trend were found.

Even though the dependence of tone durations on frequency was not significant in all sections of the music analysed in this study, three points might be drawn from the measurements of the tone durations in the different time signatures and note values as follows:

(i) The effect of frequency on the performance of tone durations is independent of the time signatures.

(ii) The effect of frequency on the performance of tone durations is independent of the note values but is more significant in the eighth-notes and quarter-notes, the dominant note values in most Western music.

(iii) The above trends are most significant for the tone durations in the range 300 to 700 msec.

No other trend was found which would account for the difference in tone durations. The position of higher notes in the musical phrases was also investigated to determine whether the following or preceding note has an influence on the performed length of a note. It is investigated whether the highest notes (and hence shortest) were in the middle of phrases. The length of notes in the middle of musical phrases, where the pitch goes up and then down, was compared with the case where the pitch goes down and then up. The highest note is F#5 and the lowest note is A4 in both cases. The average performance duration of F#5 was 287 msec and 295 msec whereas that of A4 was 304 msec and 320 msec.

Although the principle for lengthening tone duration in music has been studied [13-17], a psychoacoustic explanation has not been established. It is not clear whether performance rules for melodies, intended to eliminate an impression of mechanical performance, are dependent on properties of human perception and cognition. The experiments reported in this paper attempt to account for duration fluctuation at the note level. It has been found that high tones are played shorter and such practice has been justified in terms of previous results which demonstrate that high tones are perceived as longer than lower tones of the same physical duration [11]. When subjects were asked to produce sounds of equal length, it was also shown that the higher frequencies were played shorter [12].

In the studies of temporal integration, the effect of frequency has often been considered. Moore [18] found some evidence that the 'integration time' of the ear is shorter for high frequencies than for low. This may give the basis for a psychoacoustical explanation of why higher notes are perceived to be longer. The subjects who served in the previous auditory experiment [11] could have taken the higher tone for the longer tone because the higher tone needs less integration time to integrate sound energy for the purpose of detection.

The experiment [11] is similar to the different duration/frequency experiments (duration discrimination experiments) reported by Allan [19] in which experimental results were described for contingent duration after-effects. Allan found that perceived duration increases with an increase in frequency. Both studies [11, 19] agree on the influence of frequency on time estimation. Although this agreement might be incompatible with pure time models (Creelman, 1962; Abel, 1972; Divenyi and Danner, 1977) including the onset-offset model (Allan et al., 1971), the results of both experiments might be applied to the attentional models (Underwood and Swain, 1973; Thomas and Brown, 1974; Hicks et al., 1977; Zakay et al., 1983). An increase in frequency produces an increase in the selectivity of attention, and this leads to the conclusion that greater selectivity of attention produces a longer duration experience than a broader distribution of attention.

Merely observing that performers play higher notes faster and that listeners hear higher notes as being relatively longer than lower ones does not explain either phenomenon in isolation, nor does it demonstrate the link between these two observations. So far it seems that it is not perfectly explained either from a psychoacoustic, psychological or a musical standpoint. However, there are possibilities that performers could be compensating for their own perceptions, or attempting to 'even out' their performance in such a way as to compensate for their listeners' perceptual bias, or they might be doing so in response to other motor, cognitive, perceptual or musical demands/constraints. Although the discussion of such issues reported in this paper remains descriptive, it remains for further studies to provide additional interpretation of the results in relation to musical, psychoacoustic or psychological processes.

It is suggested that further work needs to be undertaken to verify the present work using other musical styles and instruments, and taking into account harmonic structure. This is especially so since a considerable body of research has demonstrated clear relationships between phrase structure and instantaneous tempo (e.g., Todd, 1989; 1992; Repp, 1990). In much tonal music pitch contour and phrase structure are confounding variables: higher notes appear towards the centre of phrases. Given the results from previous work (Jeon and Fricke, 1997) it seems likely that both phrase structure and pitch contribute to higher tones being performed shorter than lower tones.

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