Skilled Piano Performance: Melody Lead Caused by Dynamic Differentiation

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Introduction

Simultaneous notes in the printed score (chords) are not played strictly simultaneously by pianists. As reported in the literature, an emphasised voice is not only played louder, but additionally precedes the other voices typically by around 30ms (*melody lead;* Hartmann, 1932; Vernon, 1937; Palmer, 1989, 1996; Repp, 1996). It is still unclear whether this phenomenon is "a common expressive feature in music performance … that aids listeners in identifying the melody in multivoiced music" (Palmer, 1996, 51). An alternative hypothesis is that it may be mostly due to the timing characteristics of the piano action (*velocity artefact*, Repp, 1996) and therefore a result of a dynamic differentiation of different voices. Especially in chords played by the right hand, high correlations between velocity difference and melody lead (between melody notes and accompaniment) seem to confirm this velocity artefact assumption (Repp, 1996).

The investigated data, derived mostly from computer-monitored pianos, represents the asynchronies at the hammer-string contact points. The present study will be focused on asynchrony patterns at the finger-key contact times as well. Finger-key profiles represent what pianists initially do when striking chords. In this paper, we show that the melody lead phenomenon disappears at the finger-key level. That means that pianists tend to strike the keys almost simultaneously, and it is only the different dynamics (velocities) that result in the typical hammer-string asynchronies (*melody lead*).

Background

In considering note onset asynchronies, one has to differentiate between asynchronies that are indicated in the score (arpeggios, appoggiaturas) and asynchronies that are performed but not especially indicated in the score. For the latter, two typical types have been observed in the literature: (1) Melody precedes other voices about 30ms (*melody lead*), or (2) the melody lags in comparison to the other voices. Type 2 asynchronies occur mostly between two hands, e.g. a bass note is played clearly before the melody (*melody lag* or *bass lead*), which is well known from old recordings of piano performances. Type 1 asynchronies are more common within one hand (especially within the right hand, because melody often corresponds with the highest voice).

Note asynchronies have been studied in the literature since the 1930s, when Hartmann (1932) and the Seashore group (Vernon, 1937) made first investigations of piano performances. Hartmann used reproduction piano rolls as a data source and found mostly type 2 asynchronies. Vernon (1937) differentiated between asynchronies *within* one hand and asynchronies *between* different hands. For the former he observed Melody Lead (type 1), whereas the latter mostly show the bass note anticipation (type 2).

In the recent literature, Palmer (1989, 1996) and Repp (1996) studied the melody lead phenomenon. Palmer (1989) used MIDI keyboard recordings to analyse among other topics chord asynchronies. Six pianists played the beginning of the Mozart Sonata KV. 331 and of Brahms' op.117/1 ("Schlaf sanft, mein Kind..."). The melody leads by about 20 to 30ms; this effect decreased at unmusical performances and for melody voices in the middle of a chord (Brahms op.117/1). In a second study, melody lead was investigated exclusively (Palmer 1996). Six pianists played the first section of Chopin's Prelude op. 28/15 and the initial 16 bars of Beethoven's Bagatelle op.126/1 on a Boesendorfer computer-monitored grand piano (SE290, as in the present study). Like in the previous study, melody lead was found to increase with expressiveness, with more familiarity with a piece (the Beethoven was sight-read and repeated several times) and with skill level (expert pianists showed a larger effect than student pianists).

In a more detailed study carried out at the same time, in part with the same music, but with a more differentiated methodology, Repp (1996) evaluated three repetitions of 10 individual performances of the whole Chopin Prelude op. 28/15, a Prelude by Debussy and the 'Träumerei' by Schumann. To minimise random variation, Repp averaged over the three repetitions of each pianist. He then calculated timing deviations between the melody and each remaining voice, so that asynchronies of the right hand (within hand) and between hands could be treated separately. He found that melody lead could be explained mostly with variability in the dynamic differences between melody and accompaniment. These findings were proved by regressing dynamic differences (differences in MIDI velocity) with timing differences between melody and the other voices. The correlations were generally higher for within right hand asynchronies than for those between hands.

Palmer's (1996) correlations were only computed between melody lead and the average velocity difference between melody and accompaniment and were mostly non-significant. In her view, the anticipation of the melody voice serves primarily as a common expressive feature to communicate the performer's intention to the audience. In a perception test, listeners had to identify melody in a multi-voiced piece by rating different artificial versions: one with intensity differences and melody lead, one with melody lead only and one without any differences. The only difference in the ratings occurred between pianist and non-pianist listeners when the pianist listeners better identified intended melody hearing the melody lead version. A version with intensity differences only was not tested (Palmer, 1996, 47). However, the ratings were much higher for versions with intensity differences *and* melody lead than for those without any differences or with melody lead only.

Piano action timing properties

Considering the melody lead phenomenon, its physical background has to be clarified. The piano action shows some typical temporal properties, which are described best by Askenfelt (1990), and Askenfelt & Jansson (1990, 1991). When pressing a key, the time from its initial position to key bottom ranges between 25ms (*forte* or 5m/s final hammer velocity, FHV) and 160ms (*piano* or 1m/s FHV; Askenfelt & Jansson, 1991, 2385, see Figure 1a). At a grand piano the hammer impact times (when the hammer excites the strings) are shifted in comparison to key-bottom times. According to measurements by Askenfelt (1990, 43), the hammer impact time at a *forte* touch is about 3ms *after* the key-bottom contact and 12ms *before* the key-bottom contact at a piano attack. These data only provide a rough idea of these timing properties. They are plotted in Figure 1a, to give the overall impression.

Another measurement was made by Repp (1996), who was 'lucky' to have a Yamaha Disklavier on which the 'prelay' function failed to work, so he had the opportunity to measure roughly a grand piano's timing characteristic. He fitted a quadratic function into his measurement points, which provided a range of about 110ms corresponding to MIDI velocities between 30 and 100 (about 1 to 2ms onset deviation per velocity unit, Repp 1996, 3920).

We now have to differentiate between asynchronies at the beginning of the attack movement (finger-key contact) and asynchronies at its end (hammer-string asynchronies or key-bottom asynchronies). Computer-monitored grand pianos, like Yamaha or Boesendorfer, store time points of hammer-string impact, which provide a robust representation of the beginning of the sounding events.[1]

Aims

Almost nothing is known about finger-key asynchronies, because all electronic instruments used for acquiring performance data don't measure this parameter. However, to clarify the origin of melody lead, it is very important to consider exactly those finger-key asynchronies. When pianists stress one voice in a chord, do they hit the keys asynchronously or do they advise their fingers to initially accelerate the keys at the same instant of time, but with different velocities so that the hammers arrive at the strings at different points of time?

The following hypothesis was tested preliminarily in the present study: most of the asynchronies measured in hammer-string domain (computer-monitored pianos) will disappear in the finger-key domain. Pianists tend to accelerate the keys in synchrony, it is only different velocities that produce the typical hammer-string asynchronies, known in the literature as *melody lead*. In other words: differences in velocity account for basically all the melody lead effect (*velocity artefact*).

Therefore, the basic investigation needs of this study are:

1. To determine precisely how long a hammer needs from its zero position to excite the strings at different final hammer velocities (timing correction curve),
2. To collect a large sample of reliable data of high performance quality (expert students or concert pianists),
3. To investigate what pianists do, when they are asked to emphasise one voice,
4. To evaluate hammer-string asynchrony profiles as well as finger-key asynchronies. If a pianist's aim is finger-key synchrony, the asynchronies observed at the hammer-string level will basically disappear at finger-key level, or – at least – decrease distinctly.

In the course of this methodology, we try to prove more effectively the velocity artefact hypothesis proposed by Repp (1996) and to get a more detailed picture of what pianists are doing or are forced to do, when playing a melody louder in a chord.

Method

Materials

The *Etude* op. 10/3 (first 21 measures) and the *Ballade* op. 38 (initial section, bar 1 to 45) by Frédéric Chopin were recorded on a Boesendorfer SE290 computer-monitored concert grand piano by 22 skilled pianists (9 female and 13 male). They were professional pianists, graduate students or professors from the Vienna Music University, came well prepared to the recording sessions, but were nevertheless allowed to use the music scores during recording. Additionally the pianists were asked to play the initial 9 bars of the Ballade in two versions: once particularly stressing the melody (first voice) and once stressing the third voice (the lowest voice of the upper stave). The performance sessions were recorded onto digital audio tape (DAT) and the MIDI data from the Boesendorfer grand piano was stored on a PC's hard disc. All performances came up to a very high pianistic and musical level and contained very few errors (overall error rate for the Etude and the Ballade was 0.34% and 0.66% respectively).[2]

Apparatus

The Boesendorfer SE290 has one set of shutters at the hammers, which provides two trip points, one as the hammer crown just starts to contact the string and the other 5 mm lower. These two trip points provide two instants in time as the hammer travels upward, and the time difference between these instants yields the final hammer velocity (FHV, in meters per second), which can be transformed into MIDI velocity.[3]

The instant at which the trip point at the strings occurs is taken as note onset time.[4] The note onset times show a timing precision of 1.25 milliseconds, the FHV measurement has a counter period of about 0.04 milliseconds.

To avoid timing distortions in reproduction, the Boesendorfer SE290 uses a timing correction similar to the Yamaha's 'prelay' function, which corrects the timing deviations for the different velocities. The Boesendorfer SE system recalculates the precise timing characteristics for each key individually by running a calibration program. Unfortunately the detailed correction data was not made available to the author, but a curve was interpolated from data points provided by Wayne Stahnke, the developer of the Boesendorfer SE system (Stahnke, 2000). This timing correction curve (TCC) represents the time interval from the initial acceleration of the key (finger-key) to the hammer-string contact as a function of FHV (Fig. 1a) and MIDI velocity (Fig. 1b).

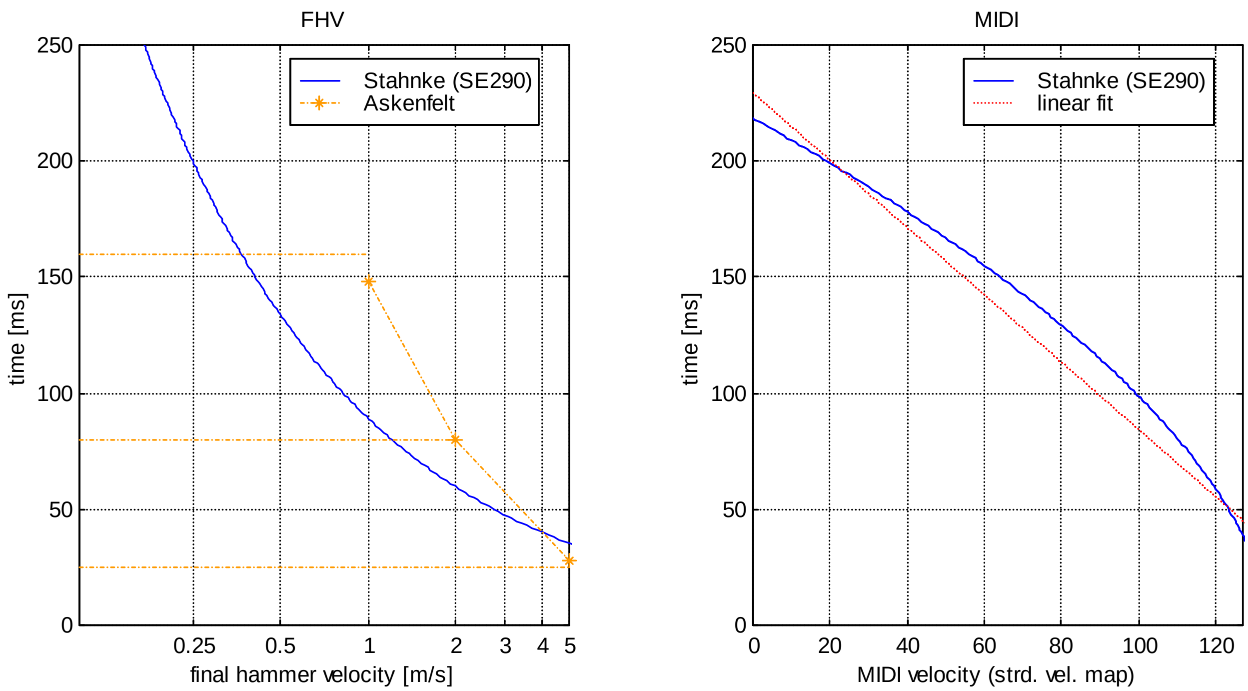

Figure 1a, 1b. The timing characteristics of a grand piano action – the hammer-string contact times as functions of final hammer velocity (left side) and MIDI velocity (right side, solid lines). The y-axes represent the time intervals from the finger-key strike times to the hammer-string contact times. The data in Figure 1a provided by Askenfelt is drawn in dotted lines with asterisks, the horizontal lines indicate the key-bottom times for the three notes (piano, mezzo forte, forte), which are temporally displaced relative to the hammer-string contact times (see text).

Procedure

All note onsets and the velocity information were extracted from the performance data. This data was corrected and matched to a symbolic score in which each voice was individually indexed. The error rate was very low (0.34% or 0.66%, see above). Wrong pitches were corrected and wrong or missing notes marked as missing. Timing differences and velocity differences between the first voice (= melody) and each other voice were calculated for each event in the score. From that, asynchrony profiles and average chord profiles can be computed that give an overview of asynchrony tendencies in the data. Missing or wrong notes, arpeggiated chords (Ballade) or appoggiaturas (Etude), as well as extreme outliers (asynchronies larger than 150ms) were not used in calculation.

Using the timing correction curve (TCC, Fig. 1a) for each hammer-string impact time the corresponding finger-key time was calculated. So, a second set of performance data was created, which represents an approximation of finger-key asynchronies. For this second data set the same asynchrony calculation procedure, explained above, was applied.

Results

Hammer-string asynchronies

The average chord profiles are shown in Fig. 2 & 3 (Etude, Ballade, solid lines with asterisks). All pianists play the first voice consistently louder than the accompaniment, so it can undoubtedly be called melody. As expected, the melody precedes other voices about 20-30 ms. In the Ballade the chord profiles are very similar to each other, melody lead slightly increases the lower the voices are. The chord profiles of the Etude show more variability, especially in the left hand, where the bass voice (7) tends to have a lead with some pianists. This corresponds to type 2 asynchrony pattern (bass lead, esp. Pianist 6, 12, 13, 14, 16 and 21). A real outlier is Pianist 3, who plays melody up to 50ms before accompaniment. In this case, it is a deliberate choice or spleen that pianist 3 uses to emphasise melody (personal communication with pianist 3).

In the exaggerated first voice versions of the first 9 bars of the Ballade, the stressed voice is played louder than in the normal version (1.4m/s versus 1.0m/s on average), while the accompaniment maintains its dynamic range. The melody lead increases up to 40 to 50ms (see Figure 4). The third voice versions show the same tendency, but to a smaller extent. The third voice is played loudest (at about 1.2m/s on average), the melody is still quite prominent (about 0.8m/s) and the other voices are as usual. The third voice leads about 20ms compared to the first voice, the remaining voices lag by another 20ms (Figure 4). Thus, when pianists are asked to emphasise one voice, they play this voice louder and enlarge the dynamic distance to the accompaniment. Parallel to this, the timing difference increases correspondingly.

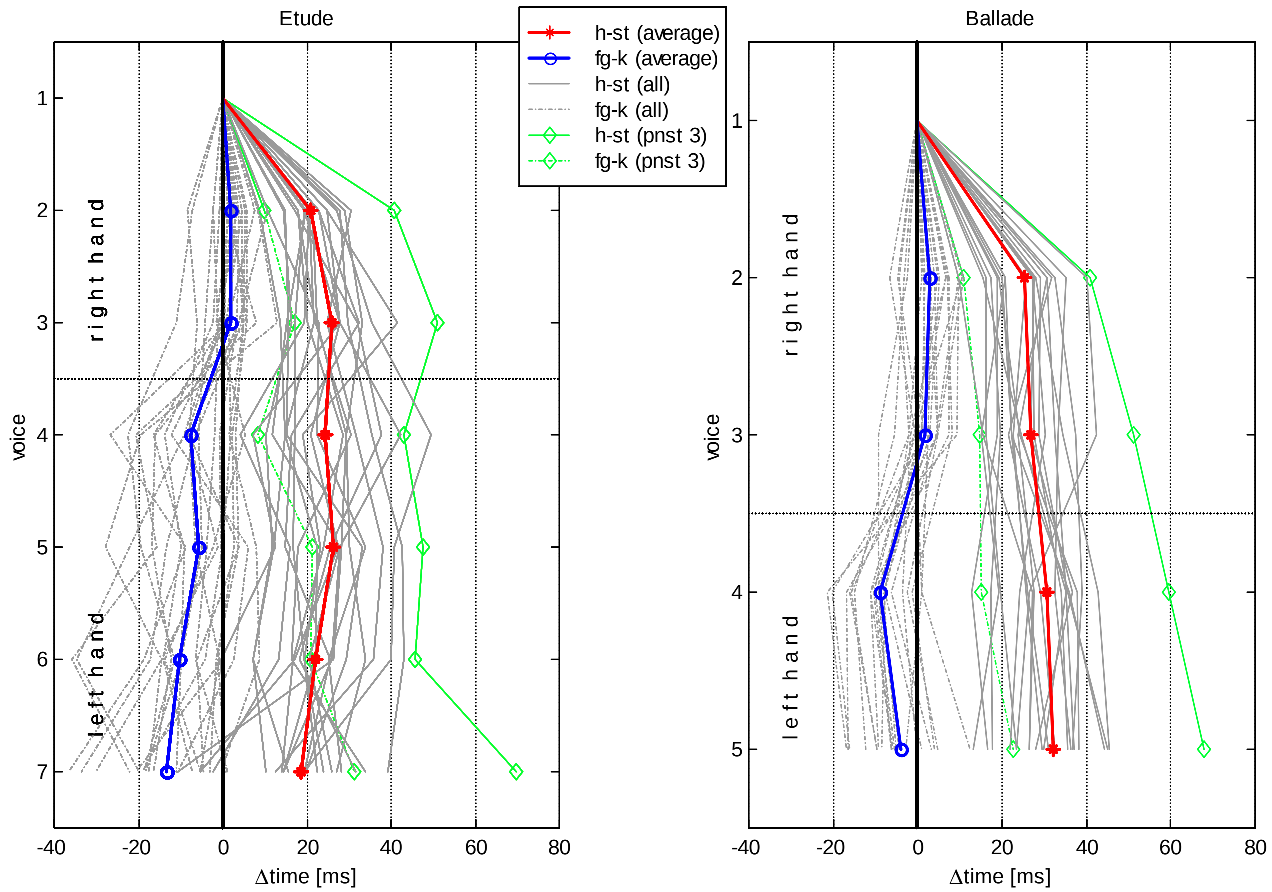

Figure 2 & 3. The average chord profiles for the average version (bold lines) and the 22 individual performances (grey lines). The profiles plot the averaged timing delays of the individual voices relative to the melody (voice 1). The right line tree (solid lines, average version with asterisks) represents the hammer-string domain (h-st); the left tree (dotted lines, average version with circles) indicates the finger-key domain (fg-k). Pianist 3 is outlined by the (coloured) lines with diamonds.

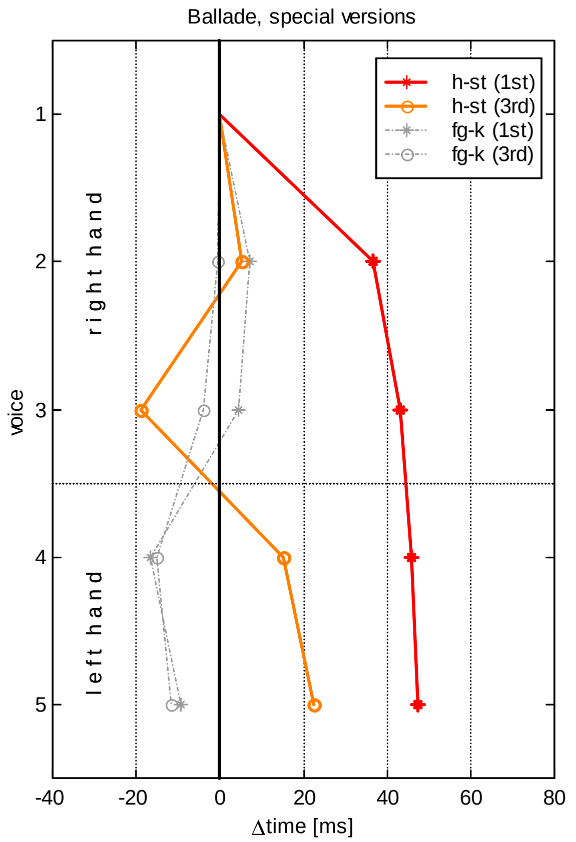

Figure 4. Average chord profiles of the 22 individual performances. The versions with the 1st & the 3rd voice stressed are indicated by asterisks or circles respectively (hammer-string domain, solid lines). The finger-key domain is plotted in dotted lines.

Generally, it can be seen that the larger the dynamic differences, the greater the extent of melody lead. This overall tendency can be measured also for each single event in the data. All velocity differences between first voice and accompaniment were regressed against their timing differences. The correlation coefficients are shown in Table 1.

Table 1. Correlations between velocity differences and timing differences for 22 recordings and their average, two pieces and two hands. The significance level is indicated by asterisks (* p < .05; ** p < .01)

Pianists	Etude r (r.h.) n_{max} = 126	 r (l.h.) n_{max} = 104	Ballade r (r.h.) n_{max} = 181	 r (l.h.) n_{max} = 269
1	-0.777**	-0.562**	-0.706**	-0.596**
2	-0.593**	-0.602**	-0.546**	-0.680**
3	-0.810**	-0.575**	-0.631**	-0.468**
4	-0.620**	-0.396**	-0.511**	-0.179**
5	-0.587**	-0.085	-0.542**	-0.564**
6	-0.771**	-0.574**	-0.653**	-0.519**
7	-0.649**	-0.478**	-0.593**	-0.512**
8	-0.606**	-0.260**	-0.360**	-0.450**
9	-0.468**	-0.228*	-0.480**	-0.402**
10	-0.670**	-0.516**	-0.562**	-0.558**
11	-0.649**	-0.241*	-0.497**	-0.572**
12	-0.704**	0.049	-0.655**	-0.299**
13	-0.622**	-0.159	-0.285**	-0.452**
14	-0.577**	-0.288**	-0.665**	-0.427**
15	-0.540**	-0.690**	-0.443**	-0.481**
16	-0.575**	0.210*	-0.619**	-0.275**
17	-0.789**	-0.372**	-0.717**	-0.703**
18	-0.704**	-0.450**	-0.510**	-0.537**
19	-0.720**	-0.421**	-0.607**	-0.603**
20	-0.802**	-0.141	-0.554**	-0.435**
21	-0.822**	-0.447**	-0.761**	-0.652**
22	-0.570**	-0.240*	-0.496**	-0.421**
average	-0.859**	-0.462**	-0.691**	-0.707**

The within right hand coefficients are usually higher than the between hand coefficients (l.h. in Table 1), more so for the Etude than for the Ballade. The lower left-hand correlations indicate a larger independence between the two hands. The often anticipated bass note is one example of this tendency, as it is displayed by Pianists 5, 12, 13, 14, 16 and 20 in the Etude. The correlation coefficients for the special versions of the Ballade show a similar picture and are not shown here.

In considering correlations of timing and velocity differences, a linear relation is measured. The timing correction curve of the piano action shows an inverse power relationship (Fig. 1). However, to get at least an impression of the slope of TCC, the FHV – MIDI velocity data was approximated by a linear curve (Fig. 1b). Figure 5 shows the scatter plots of the timing and velocity differences of the average of the 22 recordings for both hands. The interpolated slope of the TCC (-.69) is slightly steeper than the slopes of the scatter plots. The left hand slope of the Etude (-.27) is less steep, because of the asynchrony tendencies described above.

In this figure, one can see that the expected and the observed direction of the velocity artefact (slope of TCC and regression line of the average data respectively) are quite similar.

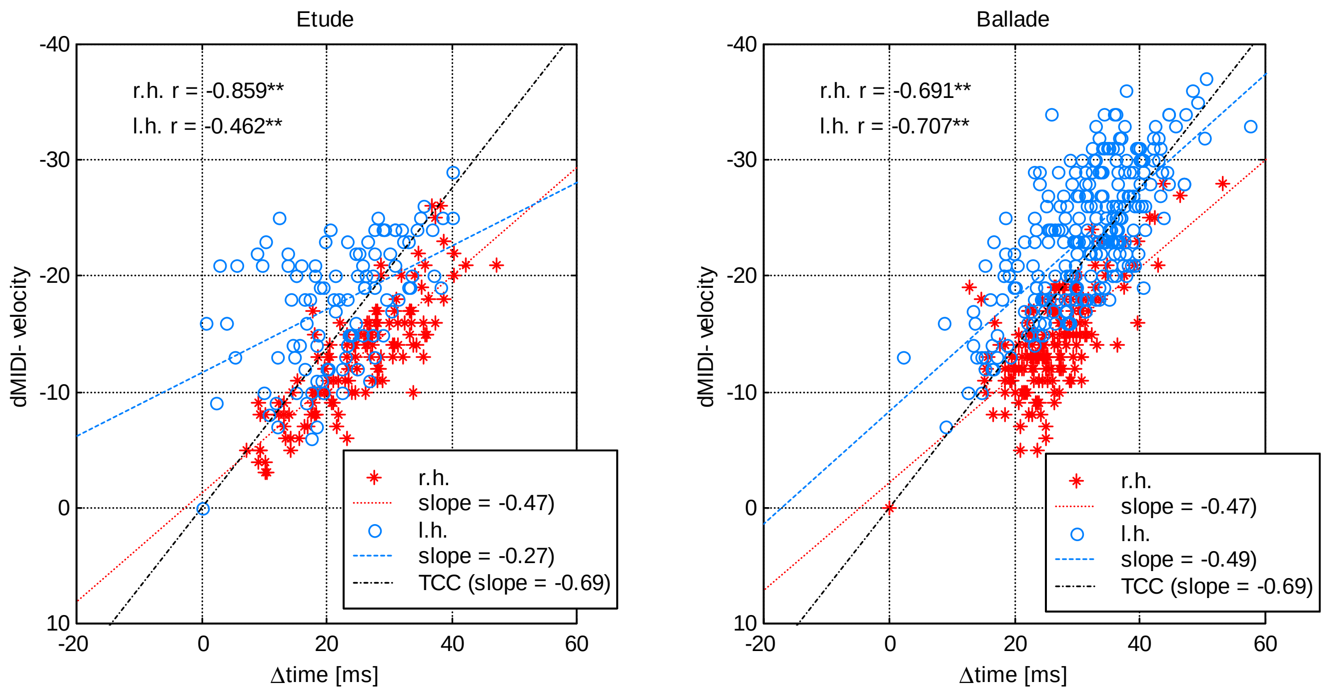

Figure 5. MIDI velocity differences against timing differences of the average of the 22 recordings. The dotted line indicates the linearly interpolated slope of the TCC function (slope = -.69).

Finger-key asynchronies

To provide an overview of the initial finger-key times, a special finger-key version for each recording was computed, where the onset times were corrected by TCC in dependence of FHV. The average chord profiles of the finger-key versions are plotted as dotted lines in Figures 2 & 3, the average finger-key chord profile of the average versions in solid lines with circles.

It can be easily seen that the chord profiles of the finger-key versions are much more synchronous than the hammer-string pattern. The melody lead for the right hand is reduced to about zero, which seems to indicate a strong effect. The differences between the hammer-string and the finger-key profiles throughout all pianists, pieces and voices are significant at $p < .01$ (two-tailed t-test), whereas the delays of the other voices relative to the melody in the finger-key profiles are all statistically non-significant ($p > .05$). This result indicates that the deviations from zero in the finger-key profiles show no striking evidence.

The grey chord profile cluster, which gives an impression of the individual chord profiles of the 22 pianists, is more homogeneous for the Ballade than for the Etude. This could be explained by the more choral texture of the Ballade. The leftward tendency in Etude's voice 4 by some pianists (5, 8, 9, 11, 12, 16 and 22) could be due to the fact that most voice 4 notes are syncopated (at the 2nd and 6th semi-quaver) and accented. So, voice 4 is only rarely played together with the bass (voice 7). It is more or less the same pianists that display large bass anticipations, so that their between-hand correlations (Table 1) become quite low and statistically non-significant.

In the special versions of the Ballade (Fig. 4) the melody lead phenomenon disappeared in the finger-key domain as well, although the stressed voice changed into the middle of the hand in the 3rd voice stressed version.

In all versions the left hand surprisingly shows a slight shift leftwards, which means that it is anticipated relative to the right hand by up to 10ms. Although this effect shows no statistical significance (see above), it can be seen throughout all versions of the Ballade and – in a slightly different way – in the Etude (Fig. 4). It is an asynchrony between hands which might be explained as a compensation tendency for a softer played hand.

In addition to this left hand leading, which is an unexpected phenomenon, another obvious asynchrony in the finger-key domain could be observed. Bass anticipations – the type 2 asynchronies mentioned above – are made by some pianists (Pianists 5, 12, 13, 14, 16 and 20), who clearly strike the bass note earlier (around 50ms, up to 150ms and higher in extreme situations).

The above mentioned Pianist 3, who plays deliberately asynchronously, still shows a reasonable melody lead of 10 to 15ms in finger-key domain (Fig. 2 & 3, diamonds). This finding suggests that intentional melody lead (pianist 3, personal communication) remains observable even in the finger-key domain.

Discussion

The consistently high correlations between timing and dynamic difference show the strong overall dependency of melody lead on velocity. The more the melody is separated dynamically from accompaniment, the more it precedes. Our way of calculation and our results coincide with Repp's study (Repp, 1996).

In addition to these findings, the finger-key versions show that most of the investigated melody lead phenomenon disappears at this level. Pianists start to strike the keys almost synchronously, which is a strong support of the overall validity of the velocity artefact assumption. They begin their acceleration basically simultaneously, but different velocities cause the hammers to arrive at the strings at different points in time.

Nevertheless, pianists clearly play asynchronously in some cases as well. First, the left hand leads globally in the finger-key domain by about 10ms, which is an unexpected result. Is it possible that pianists compensate for the longer response time of softer notes, and therefore start to strike soft chords instinctively earlier? This is – nota bene – an effect which occurs only between hands, and not within one hand. Second, as a special case of the first, the bass anticipations are extended up to 150ms in some cases and about 50ms usually, when they occur. This distinct anticipation seems to be produced by the pianist's will, although probably often unconscious.

Another interesting finding is that pianists obviously are able to enlarge the melody lead deliberately beyond the usually observed 30ms, as Pianist 3 indicates. The question is, whether it is possible for pianists to dynamically differentiate voices in a chord without producing melody lead in the hammer-string domain. In a common sense view this opposite direction seems not to be possible. There is no example in the data which would prove the opposite.

The findings of this study confirm the assumptions by Repp (1996) more than those of Palmer's studies (1989, 1996). Nevertheless, melody lead is of course a phenomenon which helps a listener to identify melody in a multi-voiced music environment. Temporally offset elements tend to be perceived as belonging to separate streams (*stream segregation*, Bregman & Pinker, 1978) and spectral masking effects are diminished by shifting one masking voice by several milliseconds (Rasch, 1978, 1979). But in the light of the present data, it doesn't seem that pianists primarily produce melody lead in order to separate voices temporally. The temporal shift of melody is more a result of differentiating voices dynamically. Melody lead is linked together with dynamic differentiation, as we have seen, however both phenomena have similar perceptual effects, that is, separating melody from accompaniment.

The TCC used to create the finger-key onset points in time is still a preliminary approximation of the grand piano's action characteristics. However, in further research a more detailed correction matrix should be obtained.

Acknowledgements

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Remarks:

[1] Palmer's (1996, 27, 29) assumption that the Boesendorfer grand piano stores key-bed or key-press impact times as note onset times contradicts information given by Stahnke (2000). Nevertheless, the melody lead effect should be even larger in key-bed (or key-bottom) asynchronies than in hammer-string asynchronies, although the difference is not large.

[2] All recordings can be downloaded in MP3 format at *http://www.ai.univie.ac.at/~wernerg*

[3] The FHV (Final Hammer Velocity) is stored in terms of Inverse Hammer Velocity, IHV, which is connected to FHV via the function

$$IHV = \frac{128}{FHV}.$$

The relation between IHV and MIDI velocity can be set deliberately by the choice of a 'velocity map'. For this study, a linear velocity map (***standard velocity map***) was chosen, which provides the relation

$$MIDIvelocity = \frac{\frac{128}{FHV} - 604.5}{-4.5}$$

whereby MIDI velocity ranges from 0 to 127 units, FHV is in m/sec.

[4] The SE has another set of shutters under the keys, which provides the note offset times and only in the case of silent notes – if the hammer doesn't touch the strings – note onsets.