The timing of grace notes in skilled musical performance at different tempi:

a preliminary case study.

Running Head: Grace note performance and tempo

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Abstract

An empirical study is reported which investigates the relationship between musical structure and the timing of 11 grace notes in 45 performances by the same performer of a short Beethoven piano piece at a range of tempi. These performances were recorded and analyzed so as to extract timing measurements, and the pianist was interviewed to gain insights into his conscious performing strategies. Significant differences in the relative length of different grace notes were found: the two grace notes with a large descending pitch interval were played significantly longer than the others. Additionally, the grace notes were timed such that they did not 'take time' from the note they are nominally attached to, but from the preceding time interval. Close attention to interview data provided by the pianist reveals that the relative timing of the grace notes corresponds to his claims that he was mimicking the motor constraints of vocalists and string players. Lastly, the data provided additional evidence against the notion that changes in overall tempo always leave the relative proportion of adjacent events invariant. Grace notes with a longer mean duration tended to deviate significantly from proportional duration, whilst shorter grace notes were roughly invariant over tempo.

Introduction

This paper focuses upon the execution of grace notes in a performance of a classical piano piece and is an attempt to address both musicological and psychological issues related to their timing. Both musicology and psychology have recently shown an increasing concern with issues in musical performance (see e.g. Rink, 1995). Such an interest in performances is in refreshing contrast to the study of notated scores, and allows the study of many musical and psychological issues that cannot be addressed through analysis of notation alone.

Within musicology, the study of historical performance practices has become a central concern. Donington (1963), for example, traces different styles of performance in baroque and pre-baroque music. From performance treatises he deduces the interpretation and application of ornamental notes and describes expressive devices in early music, such as the choice of tempo, the interpretation of meter, pulse and rhythm, and the use of articulation and dynamics. He discusses the main factors that transform a static score into a dynamic performance. This transformation, he argues, is made on the grounds of musical analysis and historically and stylistically differentiated musical conventions, which are in turn based on music theoretical interpretations and historical performance treatises. Such writings have become more than just a scholarly concern. There has been a considerable growth in the application of such historical studies to contemporary performance practice. The increasing concern with the use of historically appropriate instrumentation and style of performance has a mutual relationship with the academic study of past performance practices.

From the perspective of psychology, musical performance is considered “a rich domain for the study of cognitive and motor skills” (Palmer, 1997: 116). The aim of many studies in this field is to develop psychological theories of skilled performance by investigating the cognitive and motoric processes that influence and constrain music performance. The study of motor aspects of musical performance has led to strong hypotheses concerning time-keeping mechanisms and motor programs. It has been argued that the performance of music is co-ordinated by an internal clock or clocks and executed by a memorized motor program (see e.g. Shaffer, Clarke and Todd, 1985). This motor program contains representations of intended actions and processes that translate these into a movement sequence. It has also been suggested that further constraints upon the execution of such motoric patterns come from kinematic sources (e.g. Todd, 1995; Clarke, 1995; also see Palmer, 1997, for a review).

Psychological studies of music performance have also suggested ways of conceptualizing the mental representation of musical structures and their role in controlling and structuring temporal, dynamic and timbral variations in performances. The main theoretical concept here is that a performance conveys the musician's interpretation of the musical composition. For example, experimental research has shown that structural aspects of music such as phrase boundaries (Shaffer and Todd, 1987; Gabrielsson, 1987; Palmer, 1989; Repp, 1990; 1992; Todd, 1992) or metrical accents (Sloboda, 1983; Clarke, 1985) are marked by systematic changes in timing, articulation and/or dynamics.

A hotly debated idea in the study of motor control is the notion that the timing of a particular sequence of actions can be produced by a generalized motor program with

a variable parameter controlling the overall rate of production (Schmidt, 1985; see Gentner, 1987 for a review). In musical terms this would mean that for performances of the same piece at different tempi by the same performer the same proportions should be observed between successive time intervals between events (Repp, 1994). A piece would have a single motor program which is controlled by a timekeeper which can generate the specified movements at a range of tempi. It might therefore be suggested that the timing of the sequential events in a musical performance would thus retain not only relational invariance at different tempi, but also that the durations observed at these different tempi might be predicted by applying a scaling factor to such a function. This idea can be thought of as a "tempo curve", which, for example, might be directly derived from the hierarchical structure of the music (e.g. Todd, 1985). If both of these hypotheses are correct, a single tempo curve and some scaling factor could predict the timing of sequential events in a musical performance at two different tempi.

However, there are some doubts as to whether proportional duration is maintained at different rates of production in a number of domains, although it is unclear how much this conflicts with the notion of generalized motor programs themselves (see e.g. Gentner, 1987). Within the domain of music, conflicting evidence has been obtained regarding proportional duration. Repp (1994) has claimed that, despite some evidence against precise relational invariance, "the major (cognitively controlled) temporal… …features of a performance change roughly in proportion with tempo, whereas minor features tend to be governed by tempo-independent motoric constraints" (Repp, 1994: 269). Indeed, it has been shown that when musical materials are extremely simple (fast piano scales), both variability and note durations interact significantly with tempo (Mackenzie and Van Eerd, 1990), suggesting that Repp is correct to ascribe

some of the between tempo variance he finds to sensori-motor constraints. However, Repp (1995) has shown that in a perceptual task there was an interaction between tempo and timing for subjects' preference ratings in performances of two solo piano pieces. His results suggest that increases in tempo must be matched by decreases in relative timing variation for subjects to give equivalent aesthetic ratings of performances at different tempi. In a study of a different piece, which was faster and less romantic in style, Desain and Honing (1994) found some large deviations from proportional. They went on to claim that as well as motoric influences upon timing, there may be a strong interaction between the structural function of a particular event and its changes of duration over different tempi: its *scaling behavior*. In other words, they claimed that the durations of different events may not only scale differently with overall tempo, but that such differences might be predicted by a classification of events into different structural classes. They argued that this seriously undermines the plausibility of timing being generated from some form of tempo curve without taking into account categorical differences between different events (Desain and Honing, 1993; 1994). Such tentative hypotheses have been partly supported by studies of arpeggio and pedal timing carried out by Repp (1994; 1997a & b): he found a number of deviations from proportionality and effects of musical context.

In this article a study will be reported that focuses on the timing of grace notes. Grace notes can be seen as additional notes that ornament or 'flavor' the melody and harmony, and can be omitted or added to a performance without fundamentally changing it. A grace note is notated as a small note before a regular note and its score duration is not precisely specified. The inter-onset interval (onset to following onset duration) of a grace note is assumed to be subtracted from the following and/or previous note in the same voice (see Turk, 1789/1962; Rosenblum, 1988; Neumann,

1993). Figure 1, for example, shows a piece of Beethoven piano music with 11 numbered grace notes, each notated as a small eighth-note with a line through the stem.

Insert Figure 1 about here

Note that throughout this paper all references to the duration of grace notes concern the inter-onset interval between the onset of a grace note and the following onset in the melody voice: the onset of the *main note*. This measure is taken to avoid a conflation of note-to-note timing with articulation. The sounding duration of a grace note may extend beyond the onset of the following note within the same voice, or the grace note may have an offset that occurs before this following onset. In this paper we will confine ourselves to onset-to-onset timing and will make no attempt to study the overlap between notes.

Hence, grace notes differ from regular notes in that they have no notated duration and interact with the durations of the notes that surround them. Therefore, they are especially interesting to study from both a musicological and psychological standpoint. What factors determine the timing of grace notes? If the timing of individual events is generated from some form of underlying tempo curve each event to be produced must have some form of score representation containing the canonical relative duration of that event. Todd, for example defines this as a "metrical grid" (Todd, 1995). There are no specified score durations for grace notes, and hence some investigation is necessary to attempt to discover the performed duration of grace notes *relative* to the performed durations of notes which have known score durations if one is to say anything concrete about their timing. Similarly, one might also ask how they scale over tempo in order to be able to predict not only their duration relative to a

local musical context, but to do so for different tempi. Answering these questions will provide clues as to how grace note durations are controlled, and may also contribute to the modeling of expressive musical performance. One might also ask whether these aspects of grace note timing can be predicted by overall stylistic or historical factors, or from the specific musical context, and how independent these factors might be from sensori-motor constraints and timing variability. If grace notes vary in timing it is important to discover where this variability comes from, whether it is controlled, and whether such control reflects a representation of specific musical knowledge.

Previous research on the timing of grace notes has been inconclusive, except to show that like other aspects of musical timing, repeated performances of grace notes show some stability (Repp, 1994; Desain & Honing, 1994). This supports the notion that grace notes are under considerable timing control. Whether such stability exists equally between performances in different tempi, however remains unclear. Repp (1994) presents findings which support the notion of proportional duration over tempi for grace notes, although he notes that the grace notes in the piece used in his study may not be representative of more common types of grace notes. Desain and Honing (1994), however, find a considerable interaction between the duration of grace notes and tempo conditions. They even found that in one instance an increase in tempo was associated with an increase in the duration of a grace note, a rather surprising result. Moreover, they attempt to show that different types of grace notes, and the categories of rhythmic context in which they are embedded have different effects on their behavior over tempi. However, they do not directly test this hypothesis, and fail to account for the effect that variations in local tempo might have had on their data: it is possible, for instance, that although the overall tempi of two performances may be different, the local tempo around the location of two grace notes in the same position

in the music might be the same, or even might vary in the opposite direction. This is especially true since they show that there is a strong interaction between tempo condition and the timing of individual events. A further limitation of this study is that only three tempo conditions were studied, making any claims about scaling behavior over a range of tempi difficult to substantiate in a detailed way. Nonetheless, this study suggests that by studying grace note timing one may be able to better investigate the relationship between local musical structure, timing and tempo.

There is further support from the musicological literature for the idea that the execution of grace notes cannot be explained without taking into account local musical structure. Neumann (1986:7-8, 12; 1993: 4), for example, claims that the execution of any ornament is highly dependent on the musical context in which it is situated. For him, the execution of ornaments can only be explained by making the harmonic, rhythmic and melodic function and the context of an ornament explicit and by defining the character, style and tempo of the piece. He is particularly keen to dispense with the idea that historical tracts alone can provide 'rules' for the execution of ornaments, a practice which tends, in his opinion to result in inflexible and ugly performances, especially where a tract is applied in an inappropriate context.

Our study attempts to develop a better understanding of the production of grace notes by explicitly testing the relationship between different structural classifications of grace notes and their timing at different tempi. By collecting timing data from a musical context and analyzing the timing of grace notes that have different structural implications and are played at a wide range of different tempi, we will attempt to show that the local structure of music has a systematic effect on both the durations of grace notes and the relationship between these durations and local tempo

measurements. In this way we hope to clarify the processes necessary to control timing in musical performance, and to show that the study of psychological processes in music can benefit from detailed attention to hypotheses drawn from the musicological literature. We also hope to demonstrate that systematic empirical work on timing can make a contribution to musical knowledge. We will do this by directly studying the links between music theoretical and musicological predictions and the actual practice of a skilled musician.

Method

Music

In this study we used the theme from Beethoven's six variations in G-major WoO 70 (1795) on the duet "Nel cor più non mi sento" from the opera "La Molinara" by Giovanni Paisiello (see Figure 1). The theme was chosen for its relative simplicity and brevity. It is especially suitable for this study as it contains 11 grace notes (numbered in square boxes in Appendix 1). Moreover, it is the same theme as was used in the study by Desain and Honing (1994), thus facilitating comparison with this earlier study.

Insert Figure 1 about here

The theme is 20 bars long, consisting of an initial 8-bar phrase, followed by a 6-bar phrase, and finishing with a 6-bar phrase. Although different structural interpretations are possible, the most straightforward phrase-structure tree is depicted in Figure 2.

Insert Figure 2 about here

The first phrase consists of two sub-phrases that, in turn, can be divided into two further sub-phrases. The second phrase can be subdivided into three sub-phrases. The

third phrase consists of two sub-phrases, of which the first sub-phrase is divided into two further sub-phrases. The theme has a typical Alberti Bass (broken-chord) accompaniment. All the grace notes are notated identically. Nevertheless, they can be separated and grouped on the basis of their musical function and context in the following ways:

- All grace notes have an eighth note up-beat.
- All grace notes on the first beat of the measure are suspensions (that is, the same pitch as the former note).
- All other grace notes fall at half measure and are step-wise descending grace notes, they have the same figure: rising third, descending second, except for grace note 6: rising second and descending second.

In order to help formulate hypotheses based on structural differences between grace notes, they were classified into groups with similar features on the basis of six aspects of musical structure, as shown in Table 1.

Insert Table 1 about here

Musicological support for most of these categorizations comes from Neumann (1978; 1986; 1993) and Rosenblum (1988). Both Neumann (1993) and Rosenblum (1988) discuss the interpretation of Beethoven in relation to historical tracts and musical context - sadly, neither can provide specific advice for the interpretation of these grace notes, in this piece. However, we would like to advance a number of hypotheses in relation to these music-theoretical categorizations. First, we would

expect that grace notes that occur in different categories might have different mean durations, regardless of tempo, if these categories have some expressive significance. Note for example that grace notes 2 and 10 always occur in the same category: we would predict, for example, that these might have a significantly different duration to the other grace notes. In other words, we would expect that if one of our structural categories is expressively significant then this should lead to systematic differences in timing between grace notes within this category and the other grace notes. Differences in timing between events of different structural type or function are reported across the literature on timing in music (see Palmer, 1996; Clarke, 1985; Clarke, 1999; Gabrielsson, 1999). Second, we would predict that some of the structural categories above would encourage a relative lengthening of grace note duration for expressive purposes: some form of agogic duration accent. Such accents are a commonplace in expressive piano performance where one event is regarded as more important than another or where some form of contrast is required (Clarke, 1985). The grace notes that might be lengthened on this basis would be in (A) the grace notes with a large descending interval (2 and 10); in (B) those on a strong beat (2, 4, 5, 7 and 10); in (C) those that precede a relatively long note (2, 7, 8 and 10); in (D) those that are dissonant (2, 4, 5, 6, 8, 10); in (E) those at the beginning of a phrase unit (2, 7 and10); and in (F), those that occur at a relatively strong metrical level (2, 7 and 10). Again, 2 and 10 always seem to be candidates should be specially treated, since they occur only in categories in which we would predict lengthening.

It is hard to make any clear predictions regarding the changes in such timing over different tempi since the musicological literature provides no direct clues as to how such changes might occur. Both Neumann and Rosenblum suggest that the timing of ornamentation *should* vary with tempo, but their advice is generally too driven by

specific instances to be much help in forming systematic predictions. Accordingly, we would predict that, in accordance with Desain and Honing (1994), relational invariance will not hold, and that the relationship between timing and tempo will differ from grace note to grace note. Moreover, although we make no direct predictions regarding the position of each grace note in relation to the following note and to the accompaniment, we will attempt to see whether there is some consistent relationship between these three onsets.

Performer

A professional pianist, age 26, participated as subject in this experiment. He started taking classical piano lessons at the age of nine. He completed his studies at conservatory and has since played with several orchestras and chamber music ensembles. Currently he is a Professor of Piano at the Tilburg Conservatory in the Netherlands. The pianist was paid an appropriate fee for his services.

Procedure

Recordings were made in the "Music, Mind, Machine" laboratory on a Yamaha Disklavier MIDI grand piano. This instrument optically detects key velocities and pedal movements and converts this information to standard MIDI messages. The piano was connected by a MIDI cable to a Macintosh PowerPC 9600/233 microcomputer running Opcode Studio Vision Pro 3.5.4 (time resolution 1 ms, within the limits of MIDI transmission speed) under MacOS 8.1. An unobtrusive video-camera recorded the pianist during the experiment and the interview.

Upon arrival, the pianist was given time to accommodate and warm up. Three weeks prior to the experiment he had been asked to prepare performances of the theme at 9 different tempi, using the notation shown in Appendix 1, with the boxed numbers and direction "Thema (andantino)" removed, and told that he would have to perform the

piece five times at each tempo. The nine different tempi were 50, 52, 55, 57, 60, 63, 67, 71, and 75 dotted quarter note beats per minute. These tempi were chosen because they span a reasonable range, yet are all within the bounds of technique and our musical taste. The pianist reported that although the more extreme tempi would not be his first choices, they were musically acceptable, especially after he had accustomed himself to them through practice.

Within the experiment the pianist was instructed to play a sequence of a block of five repetitions of the theme at each of the nine tempi giving a total of 45 complete performances. The order of the tempo blocks was random, and before each block of repetitions the pianist was told the required tempo by one of the experimenters. The pianist was then allowed to practice the theme at the tempo requested (a digital metronome was provided to remind the pianist of the tempo), and was asked to indicate whenever the next five repetitions could be recorded. Between each repetition there was a short break of about 5 seconds. No feedback was given as to whether the required tempo was maintained: he was just told to concentrate on keeping the tempo as close to the required tempo while playing as musically and naturally as possible, and not to hesitate too long between repetitions. The pianist was allowed to rest between tempo conditions, but needed only one short break.

The duration of the experiment was about one hour. After completion, the pianist was asked a few questions concerning the experiment and the theme, so as to gain more information about his insights into the task, view of the musical material, and interpretative choices. Following the experiment, the timing data were stored in standard MIDI files (MMA, 1996). These files were imported into POCO, a computer environment for research on expression in music (Honing, 1990). A robust performance-score-matching facility in POCO was used (Desain, Honing and

Heijink, 1997). It transferred structural information from a score representation to the 45 performances, including the position of the grace notes, voicing, and metrical structure. At the same time, this procedure provided a secure check for performance errors. POCO was then used to extract timing measurements across performances, using this structural information to locate and measure the duration of the grace notes and other relevant events. Two statistical data-analysis programs (JMP 3.2.2 and Statview 4.5) were used for further processing and statistical analysis.

Results

To analyze the timing behavior of grace notes, the proportional inter-onset interval (IOI) of each grace note in every performance was measured. IOIs are used instead of durations, as is common in the analysis of timing in musical performance to avoid confounding timing and articulation. All IOIs in this paper are expressed in seconds. An IOI is the time elapsed between the onset of a note and the onset of the following note. It is possible to calculate the *proportional* IOI of a grace note by dividing it by the total duration of the performance. However, this will result in an unreliable measure, because tempo fluctuates during a performance. This can be seen in Figure 3, which shows the bar durations in seconds, averaged over all performances and all tempo blocks. Bar 14 is omitted since the long fermata duration (mean = 4.403, SD = .58) makes the other individual bar durations hard to see. A series of correlations was calculated between all bar durations for all 45 performances: all were significant at the .0001 level within each tempo block, suggesting that the pianist was reasonably consistent.

Insert Figure 3 about here

In order to determine whether the timing was invariant above the grace note level a two factor ANOVA was calculated, taking bar duration as the dependent variable, and tempo block (9 levels) and bar number (19 levels) as factors. The main effects of tempo ($F_{8,648} = 1518.88$, $p < .0001$) and bar number ($F_{17,648} = 89.085$, $p < .0001$) were highly significant. Moreover, the two-way interaction between these main effects was also significant ($F_{136,648} = 1.695$, $p < .0001$), suggesting that the pianist did not maintain proportional invariance across tempi even at the level of the bar.

So, instead of taking the average duration of an 8th note over the whole piece, we will use the smallest possible time span to measure tempo, which is the average duration of an 8th note within the context of each grace note. The context of each grace note is the IOI between the onset of the note preceding the grace note and the onset of the note subsequent to the note that follows the grace note. The local 8th note IOI is the context IOI divided by the number of 8th note beats it contains. We now arrive at a proportional grace note IOI by dividing the grace note IOI by the local 8th note IOI. We will express this proportion as a percentage. For example, a proportional grace note IOI of 50% means that the grace note IOI is half as long as the local 8th note IOI. Table 2 shows the mean inter-onset intervals and proportional equivalents for each grace note position across tempo blocks and repetitions.

Insert Table 2 about here

To determine the effects of local tempo and grace note position on the length of the grace notes an ANCOVA was calculated with proportional grace note IOI as a dependent variable, local 8th note IOI as a covariate (rather than taking tempo as a factor), grace note position as main effect (11 levels), and repetition (5 levels) as a

random factor. There were significant main effects of position ($F_{10, 469} = 2.2871$, $p = 0.0127$) and local 8th note IOI ($F_{1, 469} = 38.1755$, $p < 0.0001$). Moreover there was a significant interaction between position and local 8th IOI ($F_{10, 469} = 4.5418$, $p < 0.001$. A more detailed analysis of each of the significant effects follows.

We will first focus on the effect of position on proportional grace note IOI. Figure 4 shows for each position the mean proportional grace note IOI. Grace notes 2 and 10 both have the largest average proportional IOI. A Tukey-Kramer mean comparison between all grace notes shows that only grace note 2 and 10 have means that are not significantly different from each other, but significantly different to all the other means (at a 0.05 significance level). We will offer an explanation of why these two grace notes should be played relatively long in the discussion section below.

Insert Figure 4 about here

Next, Figure 5 illustrates the effect of local 8th note IOI on proportional grace note IOI across all grace note positions and repetitions, taking proportional grace note IOI as the dependent variable and local 8th note IOI as the predictor. This is equivalent to the test for proportional invariance described in Gentner (1987). If the grace note IOIs were timed proportionally with changes in tempo one would expect a regression with a non-significant slope. This was not the case here: a small regression effect was found ($R^2(494) = .104$, $p < .0001$) with a significant positive slope. This means that the grace note IOIs are not relationally invariant with local 8th note IOI. As the local 8th note IOIs get longer, the grace note IOIs increase more than would be expected from a proportional duration model. In other words, when tempo decreases, the grace note IOIs are lengthened more than notes in their surrounding context.

Insert Figure 5 about here

Along with the main effect of local 8th note IOI, there was a significant interaction between local 8th note IOI and grace note position on proportional grace note IOI. This means that the grace note IOI scaling behavior is different depending on the position of the grace note within the piece. Separate linear regressions were calculated between proportional grace note IOI and local 8th note IOI for each grace note position. The results are shown in Table 3. For grace notes 2, 7, 8, 9, and 10 a significant regression was found with a positive slope. For all other grace notes, the mean proportional IOI was the best predictor. This means that in only half the cases could anything like proportional duration be claimed, which is rather more than the 10% rejection rate required by Gentner (1987) for a series of tests of this kind. In other words, grace note timing is not proportional over tempi for this pianist playing this piece.

Insert Table 3 about here

The significant regression lines are plotted in Figure 6. Clearly, the slopes of the regressions associated with positions 2 and 10 are greater than those for the others, with 7 and 8 coming close behind. Position 9 is barely significant. Grace notes 2, 7, 8 and 10 also have the greatest mean proportional IOIs, suggesting either longer notes change more than shorter ones, or that some underlying factor has an effect on both duration and scaling.

Insert Figure 6 about here

To test whether any of the music-theoretical categories described above had an effect on grace note IOIs a multiple regression analysis was carried out which took proportional grace note IOI as the dependent variable and regressed it against local tempo (to take account of the non-proportionality), and 5 structural variables which

were condensed from the classifications given in the method section. These variables were Interval Before, Interval After, Harmony After, Harmony Before and Metrical Weight. The variable levels are shown in Table 4, below. A category which corresponded to the rhythmic ratios between the events before and after the grace note was too highly correlated with Interval Before to be used.

Insert Table 4 about here

The multiple regression was significant overall ($F_{6,488}$ = 99.904, p < .0001) and although the majority of the variance was accounted for by the changes in local tempo (F = 35.279) the most significant was Interval After (t = 13.129, p <.0001), closely followed by Interval Before (t = -6.898, p <.0001), local 8th note IOI (t = 6.068, p <.0001), Metrical Weight (t = -3.485, p = .0005), and Harmony After (t = -2.816, p = .0051). Harmony Before was non-significant.

In order to describe the relative positioning of grace notes, we expressed the onsets of each grace note and its following melody note (hereafter: main note) relative to the onset of the accompaniment note (coinciding with the main note) over local 8th note IOI. Figure 7 shows the relative timing in seconds of the main note and grace note, taking the accompaniment note in the left-hand as a reference. Note onsets that occur before the accompaniment are negative; those following it are positive. Also plotted on the scattergram are regression lines for relative main note timing versus local 8th note IOI and relative grace note timing versus local 8th note IOI.

Insert Figure 7 about here

The increasing distance between the regression lines expresses the scaling of the IOIs with tempo. The relationship between main note and accompaniment note remains constant over tempo, with a mean asynchrony of 0.012 seconds: the regression is not

significant. Therefore, the increase in grace note IOI does not create a corresponding increase in left-right hand asynchrony and the main note tends to lead the accompaniment across the range of local tempi. Moreover, the increasing duration between grace note and main note over tempo suggests that as the grace notes scale with tempo their onsets occur earlier relative to both main note and accompaniment note, rather than by displacing the onset of the main note later and later.

Discussion

There are four topics we would like to address here. We will argue that there are at least two different categories of grace notes in this piece, that the grace note IOI can be predicted partly from structural classifications of the grace notes, that relatively long grace notes scale differently over tempo than relatively short grace notes, and that there is a consistent relationship between grace note onset, main note onset and right-hand note onset. Of course, these findings apply to only one performer, to one piece and to one musical style. However, although this makes general claims problematic, we would like to stress that in this study a decision was made to obtain a detailed understanding of a single performer and piece through the collection and analysis of a relatively large dataset of repeated performances. Another performer might exhibit different patterns of timing, and our performer might well have performed a different piece or style of music in a rather different manner.

Our results show that grace notes 2 and 10 are consistently and significantly played longer than the other grace notes over all the different tempi. Our hypothesis regarding this effect was that grace notes in different music-theoretical categories would be played differently, regardless of tempo. Indeed, a classification by melodic

configuration (leap *versus* step) makes a separate category of grace notes 2 and 10, with grace notes with a following leap having a longer proportional IOI. Desain and Honing (1994) suggest a classification of appogiature (grace notes 2 and 10) and accacciature (the others). Their classification is supported by our findings, although we would take issue with their application of these particular names (see below). Grace notes which repeat the note before are also played longer, as are those which occur on the first beat of the bar and those that are consonant with the following chord. It would seem reasonable to conclude that this pianist is accentuating grace notes which proceed by leap to the following melody note, as well as accentuating the first event of the bar. The note repetition effect is hard to interpret, but could either be due to a motoric limitation (or a compensation) or an attempt to re-emphasize the same pitch. The relationship between harmonic and intervallic effects on the timing of the grace notes and stylistic issues will be returned to below.

We would, therefore, argue that melodic configuration and more particularly, the interval directly following the grace note, is predominant in determining the length of a grace note. Our pianist confirmed this in his comments after the experiment by saying “[grace notes] 2 and 10 are striking, because they span such a large interval. A singer or a cellist needs a lot of time to make that jump and [lengthening the grace notes] makes the grace notes more expressive.” Our findings are in agreement with these comments. Although there is no technical reason for the pianist to lengthen these particular intervals, he consciously aims to do so in order to mimic the technical constraints other musical instruments entail. The pianist's execution of these intervals is not, as far as we can see, limited by mainly motoric factors, but by an interpretative decision based on a desire to mimic other instruments. It should be noted that the original melody was intended as a vocal piece: we might speculate that, in this case,

the pianist is attempting to evoke this provenance in his interpretation. In other words, a technical constraint on one instrument is in this case translated into an expressive strategy on another.

Figure 6 showed that different grace notes scale differently over tempo than others. In particular, grace notes 2, 7, 8, 9 and 10 scale significantly more than would be expected if grace note timing were relationally invariant. There is no single music-theoretical category into which these grace notes fall. It is therefore difficult to make any definitive statement regarding why this effect should occur, but it does seem that longer grace notes scale more over tempo than shorter ones. Whether this is due to some general timing principle, such that longer intervals simply tend to scale more with tempo, is impossible to ascertain from this study alone. What is more certain is that for this highly skilled pianist, consistent deviations for proportional duration may be observed and we would argue that this is strong evidence against relational invariance in musical timing. These results are in contrast to Repp's (1994) finding that grace notes were relationally invariant over tempo. Our results do not, however, replicate the findings of Desain and Honing (1994). They found that, although grace notes 4 and 5 occur in very similar situations, they were treated in a radically different way: grace note 4 became slightly longer as the tempo became lower, whereas grace note 5 became shorter. Similarly, although grace notes 3 and 11 are virtually identical, they found a significant difference between the two. Desain and Honing do remark that more data were needed to come to a precise description and explanation of these different behaviors of the grace notes. We found no evidence that our pianist treated grace notes 4 and 5, or grace notes 3 and 11 in a different way.

Although we cannot say anything about the absolute placement of the grace notes we can make some definitive statements about their relative placement. Figure 7 shows

that all the grace notes consistently occur before the reference point (the left-hand note) and that the main note occurs some 12 ms before the reference point. This last phenomenon can be explained by the fact that the main note is the melody note and therefore leads the accompaniment (Palmer, 1989). The grace note occurs earlier and earlier when the tempo gets lower and does not push the main note back relative to the accompaniment note as it gets longer. Such a pattern of timing does not fit in with the two types of ornament identified by Desain and Honing (1994): appogiature or acciaccature. Both these types of ornament are normally assumed to be played such that they occur at the same time as the other onsets of the harmonic context (in this case the left-hand onset). In the case of an appogiatura, the following note is delayed significantly. One might expect to find evidence for appogiature in an increasing asynchrony between left and right hand, with the right hand occurring later than the left. This is not what is found in our study. Neither does our study give evidence for the grace notes being acciaccature. In the case of the accacciatura the grace note and the following note are played simultaneously, with the grace note being released quite quickly. (see Neumann, 1986: 42) However, leaving aside the precise musicological distinctions between these types of ornament, it is clear that the pianist is making a distinction between long and short grace notes, and playing them such that they take time from the preceding note. This actually makes considerable musical sense. When the grace note takes time from the preceding note, instead of the following note, the regular rhythm of triplets and the irregular rhythm of quarter note plus eighth note of the melody are maintained. If the grace note is played in the time of the main note, it distorts the regular rhythm of triplets, by making the rhythm irregular and it distorts the 2 to 1 ratio of the irregular rhythm, by making it regular (1:1:1) or unidentifiable. Another explanation is that grace notes might be played as if their duration comes

from the preceding note where they are considered more strongly attached to this note than to the subsequent note. All the grace notes in this piece apart from grace note 6 either elaborate the harmony of the previous note, or simply repeat the same pitch. Grace note 6 however, is an unprepared suspension, a semitone above the following melody note. This grace note takes up an interval of less than 20% of an eighth note: it has the shortest mean proportional IOI of all the grace notes. It takes time from the previous note, since the mean asynchrony between main right hand note and left hand remains negative across the 45 repetitions of grace note 6. A possible explanation for the timing of this grace note is that the performer was actively avoiding accentuating the dissonance between grace note 6 and the left hand note, by playing the grace note before the left hand onset and keeping its IOI relatively short. This is in line with our finding that all the grace notes which are dissonant with the following harmony are played shorter. One might further speculate that this was in line with the pianist's explicit attention to the sung character of the melody:

> "I also thought about how to play the grace notes: that's a difficult matter. There are of course official rules for this, but I thought: if I were a singer, how would I do it? It's important where you place the grace note [plays the 2nd grace note in different ways]. Based on my intuition, hoping that's correct, I decided to play them just before, so the listener has time to experience the interval downwards. If I would play it on the beat it would be stressed too much… With the authentic performance practice, there are of course a lot of rules about everything, but with a songlike theme like this one, you can be freer. Of course, you have to pay attention to what sounds comfortable."

Conclusions

In this study, although our findings are confined to the study of one expert performer's performances of a single piece, we believe a number of firm conclusions may be drawn regarding the timing of grace notes. The most important of these is that although musical structure may have an important influence upon their execution, such structural factors cannot alone explain the differences we find in the relative length of grace. Instead, the major influence on grace note timing seems to be stylistic. The "character" of the melody, its origin in an operatic aria, combines with local differences in interval structure, small and large melodic leaps, resulting in subtle interpretative decisions that influence the length allotted to each grace note.

In addition, this study considerably weakens the notion that grace note timing can be explained by any theory that predicts relational invariance across a range of tempi. Although we cannot propose any substantive theory to explain why certain grace notes in this study were relationally invariant, and others not, it seems unlikely to us that this result could be explained by motoric constraints alone. Although it remains unclear what factors may play a role in changing the relative lengths of grace notes at different tempi, it is clear that subtle stylistic factors might again have played a role. As the pianist noted:

> "You can always make a tempo sensible. But the tempo shouldn't make the piece too jumpy, nor too dreamy and romantic. I would look for something songlike and simple."

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Tables

Table 1

Categorization	**Categories**	**Grace Notes**
Melodic configuration	Note repeat with descending sixth	2, 10
	Note repeat with descending second	4, 5, 7, 8
	Rising third, descending second	1, 3, 9, 11
	Rising second, descending second	6
Metrical position	Strong beat	2, 4, 5, 7, 10
	Weak beat	1, 3, 6, 8, 9, 11
Rhythmic configuration following the grace note	Three eighth notes	1, 3, 6, 9, 11
	Dotted eighth note and eighth note	4, 5
	Quarter and eighth note	2, 7, 8, 10
Harmonic configuration Grace note is:	Dissonant	2, 4, 5, 6, 8, 10
	Consonant non-chord tones	1, 3, 9, 11
	Chord tone	7
Phrase position	Beginning of two bar phrase	2, 7, 10
	Middle of two bar phrase	1, 3, 6, 8, 9, 11
	End of two bar phrase	4, 5
Position in greater metrical framework, or longer-term phrase structure	Relatively weak metrical level	1, 3, 6, 8, 9, 11
	Intermediately strong metrical level	4, 5
	Relatively strong metrical level	2, 7, 10

Table 2

Grace Note Number	Grace Note IOI (SD)	Proportional Grace Note IOI (% of Average 8th Note IOI within context)
1	.063 (.013)	18.872
2	.124 (.041)	34.571
3	.069 (.016)	21.106
4	.078 (.018)	22.497
5	.084 (.018)	24.434
6	.06 (.014)	17.118
7	.097 (.024)	26.646
8	.08 (.019)	25.508
9	.068 (.017)	20.575
10	.125 (.041)	33.346
11	.068 (.013)	20.569

Table 3

Grace Note	R squared	p =	Mean proportional IOI	Regression Equation (Y = proportional grace note IOI; X = local 8th-note IOI)
1	0.01	n.s.	.189	Y = .156 + .1 * X
2	0.33	< 0.0001	.346	Y = -.14 + 1.373 * X
3	0.007	n.s.	.211	Y = .172 + .119 * X
4	0.07	n.s.	.225	Y = .145 + .233 * X
5	0.006	n.s.	.244	Y = .22 + .072 * X
6	0.04	n.s.	.171	Y = .107 + .183 * X
7	0.17	0.005	.266	Y = .133 + .37 * X
8	0.14	0.01	.255	Y = .104 + .489 * X
9	0.09	0.04	.206	Y = .088 + .357 * X
10	0.14	0.01	.333	Y = .05 + .766 * X
11	0.01	n.s.	.206	Y = .247 - .124 * X

Table 4

Variable Name	**Levels**	**Grace Notes in Category**
Interval Before (grace note)	Unison	2, 4, 5, 7, 8, 10
	Stepwise or small leap	1, 3, 6, 9, 11
Interval After (grace note)	Stepwise	2, 10
	Leap	1, 3, 4, 5, 6, 7, 8, 9, 11
Harmony Before (grace note)	Grace Note Consonant	1, 2, 3, 4, 5, 7, 8, 9, 10, 11
	Grace Note Dissonant	6
Harmony After (grace note)	Grace Note Consonant	1, 3, 7, 9, 11
	Grace Note Dissonant	2, 4, 5, 6, 8, 10
Metrical Weight (at grace note)	Stronger (start of bar)	2, 4, 5, 7, 10
	Weaker (mid-bar)	1, 3, 6, 8, 9, 11

Figure Captions

Figure 1

The score of the Beethoven piano piece. The version given to the pianist omitted the numbers in boxes which identify each grace note.

Figure 2

The theme represented as a hierarchy of phrases.

Figure 3

Mean duration for each bar across all 45 performances. Error bars represent 1 standard deviation. Note that bar 14 (which is left outside the boundaries of the chart so as not to distort the smaller changes in duration between the other bars) contains a fermata and bar 8 a major phrase boundary.

Figure 4

Mean proportional IOIs for each grace note across all performances. Capped bars represent 1 standard deviation.

Figure 5

The relationship between local 8th note IOI (local tempo) and the proportional grace note IOIs. The 11 grace notes from each performance are differentiated by point type and a linear regression line is shown for all 495 grace notes.

Figure 6

The relationship between local 8th note IOI (local tempo) and the proportional grace note IOIs. The 11 grace notes from each performance are differentiated by point type and linear regression lines are plotted for the five grace notes where there is a significant linear fit. See figure 5 for key.

Figure 7

The onset times of grace note and main note relative to the accompaniment onset (see text). Regression lines show the significant linear relationship between the relative onsets of the grace notes and local tempo, and the non-significant linear relationship between main note onset and local tempo.

Figure 1

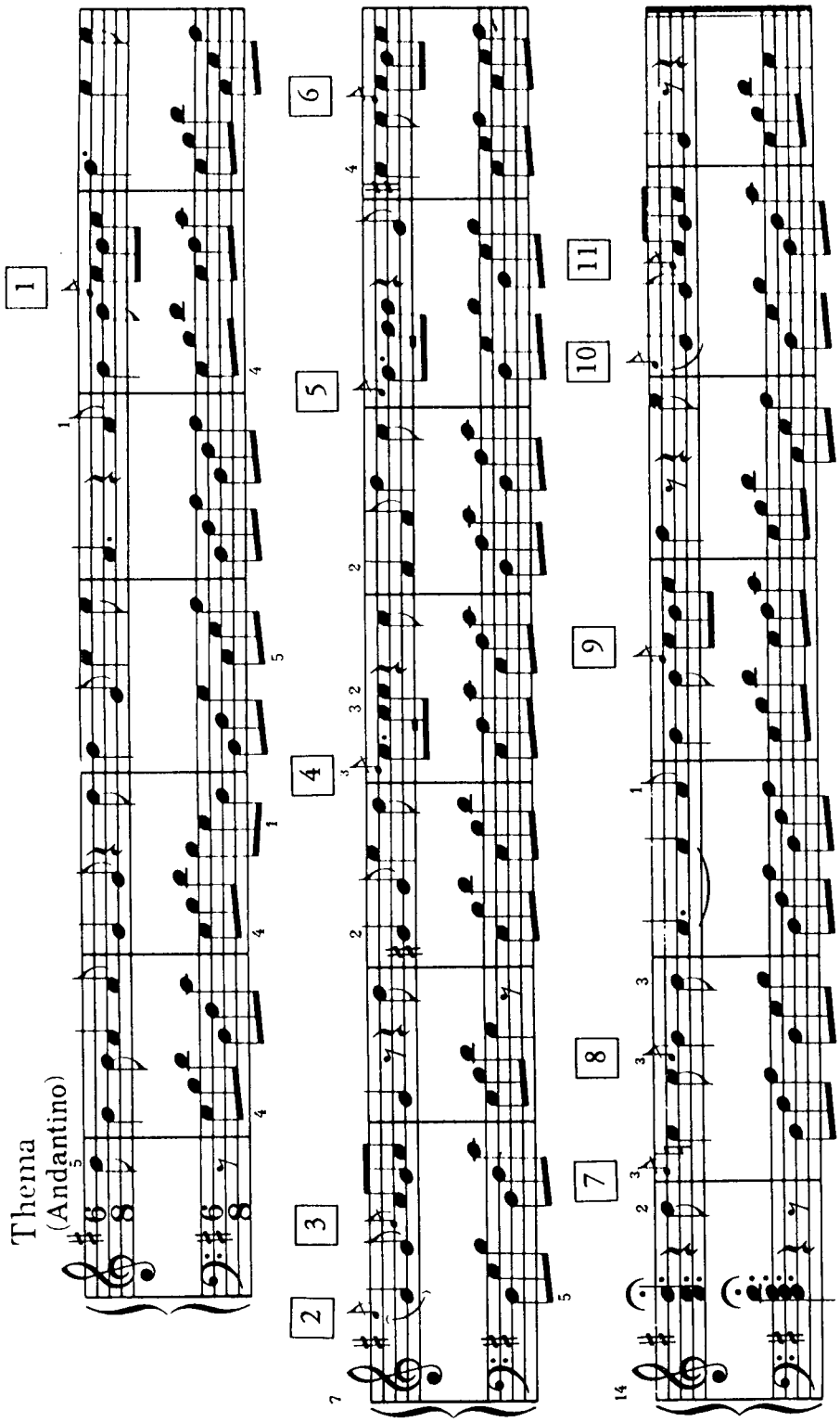


Figure 2

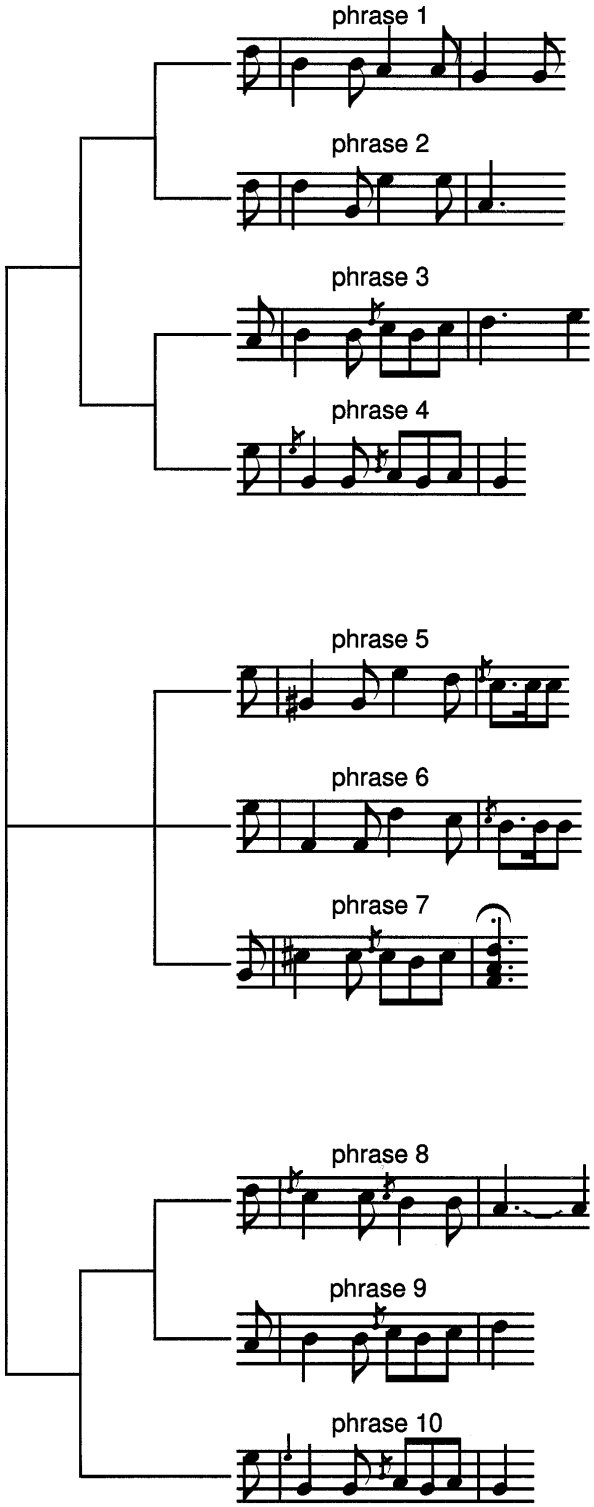

phrase 1
phrase 2
phrase 3
phrase 4
phrase 5
phrase 6
phrase 7
phrase 8
phrase 9
phrase 10

Figure 3

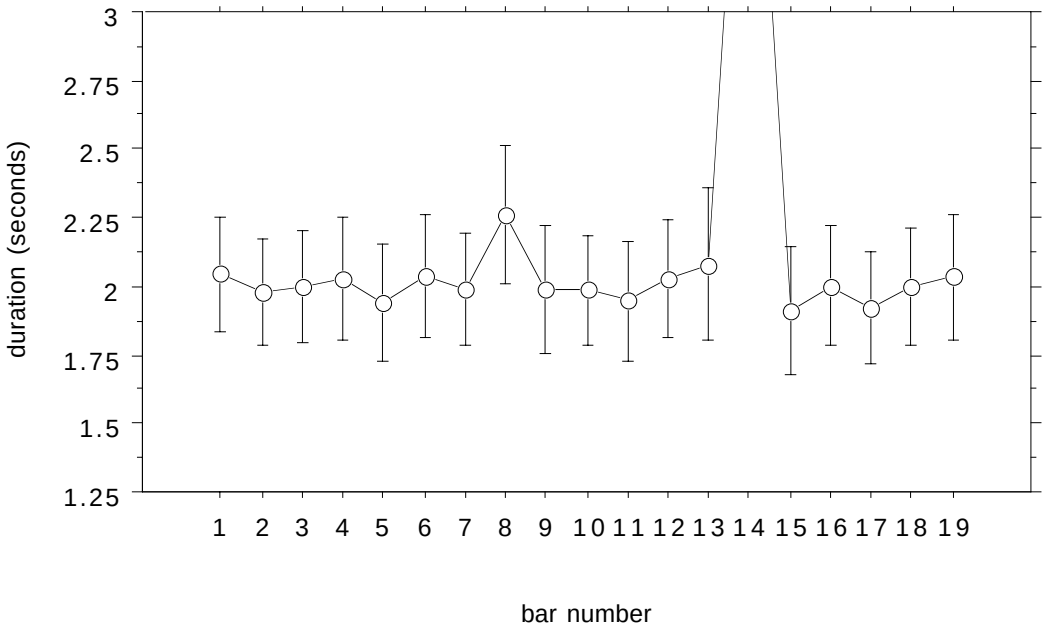

duration (seconds)
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
bar number

Figure 4

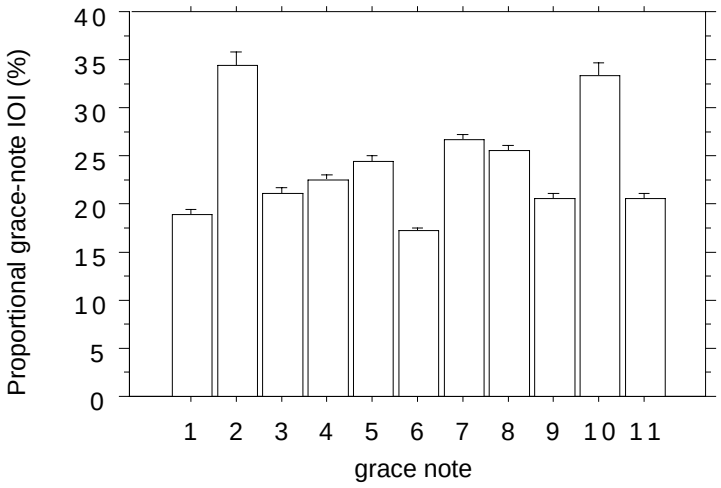
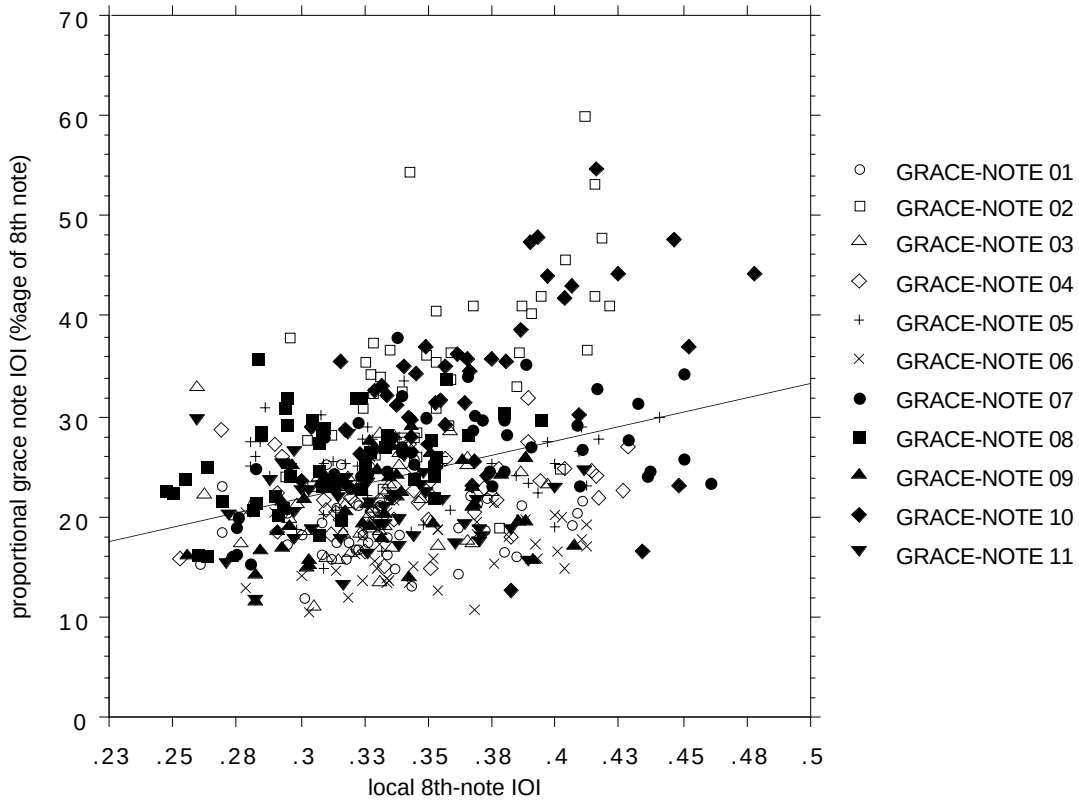

Proportional grace-note IOI (%)
0
5
10
15
20
25
30
35
40
1
2
3
4
5
6
7
8
9
10
11
grace note

Figure 5



proportional grace note IOI (%age of 8th note) = 4.654 + 57.054 * local 8th-note IOI; R^2 = .104

Figure 6

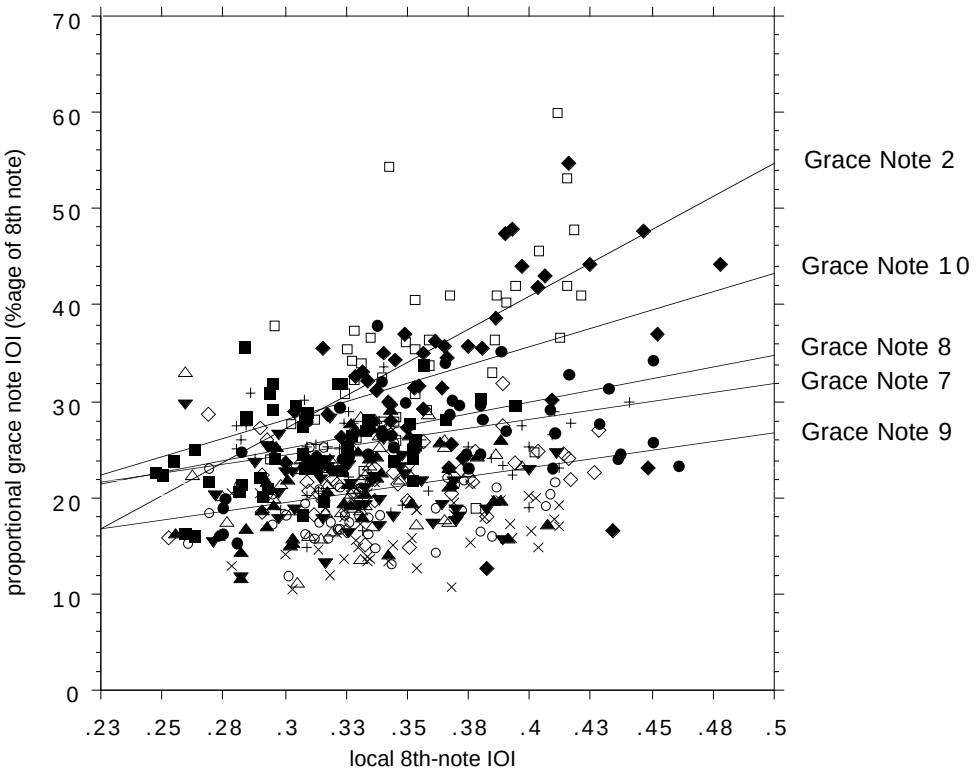
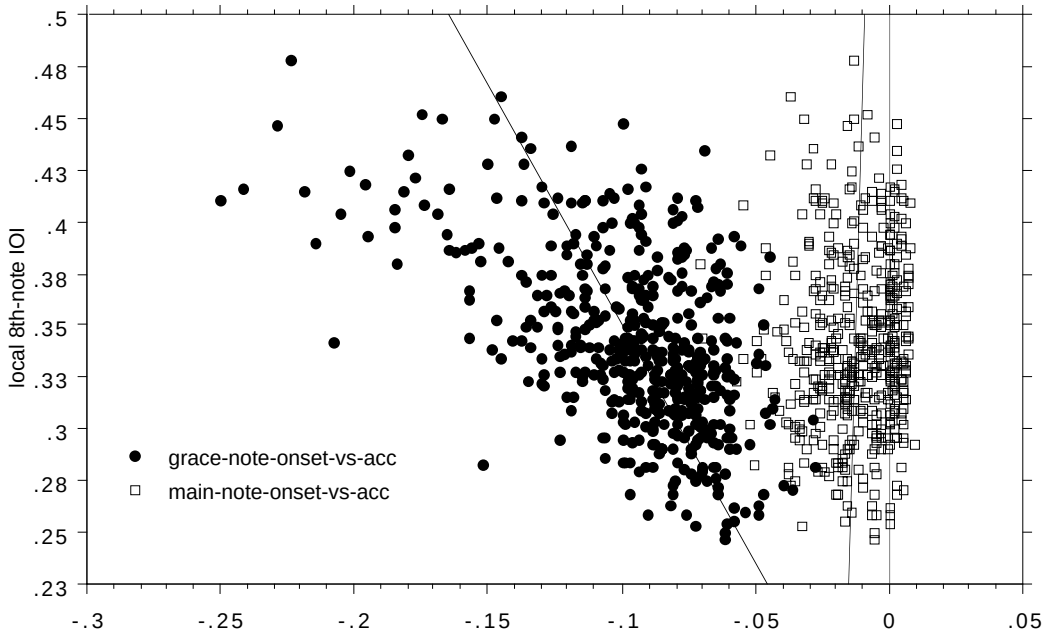

70
60
50
40
30
20
10
0
proportional grace note IOI (%age of 8th note)
.23
.25
.28
.3
.33
.35
.38
.4
.43
.45
.48
.5
local 8th-note IOI
Grace Note 2
Grace Note 10
Grace Note 8
Grace Note 7
Grace Note 9

Figure 7



grace-note-onset-vs-acc = .052 - .434 * local 8th-note IOI; R^2 = .301
note-onset-vs-acc = -.019 + .02 * local 8th-note IOI; R^2 = .004