Timing of ornaments in the theme from Beethoven's *Paisiello Variations*: Empirical Data and a Model

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Abstract

Musicians have to make many interpretive decisions when performing a piece. For example, the grace note, a one-note musical ornament, has no precise duration written in the score; it has to steal its duration from either the preceding or following melody notes. The empirical questions this study seeks to answer are: what duration grace notes are given; whether this varies depending upon musical context or individual differences; and whether their durations are subtracted from the preceding or subsequent melody note, or by inserting additional duration and leaving these preceding and subsequent durations unchanged.

In an experiment, sixteen professional pianists performed three musical fragments (from a Beethoven Theme) 'with' and 'without' grace notes in seven different. The timing of the grace notes is found not to be proportional to changes in global tempo for most, but not all performers, replicating earlier studies. In the majority of cases increases in bar duration are matched by smaller relative increases in grace note duration than predicted by a proportional tempo model, with a minority of subjects performing grace notes with fixed duration over tempo. In most cases grace note duration was 'stolen' from the preceding melody note, with a small contribution from the following (main) note, and with minimal disturbance to local tempo; conversely, where grace notes were played as appoggiatura the main source of their duration was the main note. The type of grace note performed depends both on its musical context and individual differences between performers. A model of grace note duration is proposed to account for these results.

Introduction

Musical ornamentation is the process by which a notated or otherwise canonically specified piece of music is elaborated upon by a performer, largely through the addition of additional note events. Such additions may be indicated through more or less specific notational convention, as in the case of notated trills or grace notes, or may be left up to the performer: even where ornaments are not specified in a score, there are performance practices that allow for (or demand) from the performer melodic elaborations which can alter a melody quite considerably. Ornamentation not only changes the melodic structure of a piece, but also its rhythmic structure. Such rhythmic modifications may operate by the insertion of extra duration (as in an ornamented fermata) or by occupying some of the duration of neighboring notes without otherwise disturbing the flow of local tempo. In a limited sense, both these rhythmic modifications can be considered extreme forms of expressive timing (tempo rubato), although unlike rubato they can often be transcribed with precise canonic durations, as in the case of a written-out mordent.

There are a host of questions that arise in connection with ornaments; foremost among these are the interpretation of the figures indicated by various notational conventions (for an overview, see Donington (1989)). In particular, the rhythmic dimensions of different classes of ornaments are open to differing interpretations. Not only do contemporary sources (such as the eighteenth-century treatises of C.P.E. Bach (1780), J. Quantz (1752), and F. Geminiani (1749)) and modern scholars (compare, for example Donington (1989), with Neumann (1993)) show considerable disagreement, they also fail to offer precise instructions, noting the importance of local and global musical contexts. This is the case even if only one class of ornaments, such as those we now refer to as ‘grace notes’, is

taken by itself. This is especially so in the area of rhythm, where both the time-placement of the ornament relative to simultaneously-sounding notes and the duration of the ornamental notes may be left largely up to the player's judgement. In response to such uncertainty and ambiguity, the primary motivation for this study is to determine empirically how particular musical contexts affect the duration of grace notes, and whether such effects of context vary between performers.

A second motivation for this study is the controversial role that grace notes have played in the study of the relationship between expressive timing and global performance tempo. Repp (1994) has argued that the relational invariance hypothesis (Schmidt, 1985) applies as strongly to music as it seems to for many aspects of general motor behavior. He proposes that the duration of a musical event is characterized by its ratio to the duration of the whole, regardless of changes in global tempo. Thus, the durations of individual events scale proportionally: a faster performance will result in a shorter event, maintaining a fixed ratio relation between the two durations. In other words, the duration of each note of a piece scales proportionally with the duration of the piece itself. Repp (1994) found evidence in support of this: he instructed pianists to perform the same piece ("Traumerei" by Schumann) at different tempi and observed no significant deviation from relational invariance. One may even be tempted to interpret the widespread availability of tempo controls on commercial music synthesizers and software, which speed up and slow down performances in just this way, as ecological evidence of the validity of this approach. However, when analyzing expressive timing data from two other pieces (theme and first variation of “Paisiello” Variations WoO 70 by Beethoven), Desain and Honing (1994) found evidence for the non-proportional scalability of timing with tempo.

Similarly, the swing rhythm, a typical jazz figure, is not relationally invariant with tempo (Friberg, & Sundström 1999). One possible reason for such lack of relational invariance could be that the tactus level and span of groups changes with tempo which will influence the timing profile (Clarke, 1985). Most importantly to this paper, and contrary to Repp (1994), two studies have shown significant deviations from relational invariance in the timing of grace notes at different tempi (Desain and Honing, 1994; Windsor, Desain, Aarts, Heijink and Timmers, in press).

This study's primary concern is to understand the duration and timing of the grace notes within their musical contexts and at different tempi. Secondly, we aim to gather the necessary data to model the position of a grace note with respect to its surrounding notes and the changes in timing produced when a grace note is inserted. Both aims come with the caveat that different types of grace notes may exist and behave differently. A third aim is to identify these differences and the different musical contexts with which they are associated.

This study seeks to improve upon the three existing studies of grace note timing (Repp, 1994; Desain and Honing, 1994; Windsor et al., in press). Firstly, unlike these precursors, short musical fragments are recorded in an attempt to minimize any effects of tempo drift over the course of a performance (a problem encountered in Windsor et al., in press). Secondly, because each musical fragment is played with and without its corresponding grace note, we are able to capture any resulting changes in its timing, which provides a distinction between timing originating from the whole and the timing of the grace note only. Thirdly, strict tempo control allows for direct comparison of timing profiles without

the need of normalization. Lastly, the generality of the results across pianists is assured by taking 16 professional pianists as subjects.

Method

Material

Three musical fragments were used from the theme of Ludwig von 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[1]. All fragments contain one measure of introduction, three and a half measure**s** of natural performance and a pause of a length randomly varying between 0.5 and 1.5 measures (see figures 1-3). The grace note occurs after one and a half measures of the natural performance (see small notes in scores). The endings of fragments 1 and 3 were composed for the purposes of this study by adding the last chord.

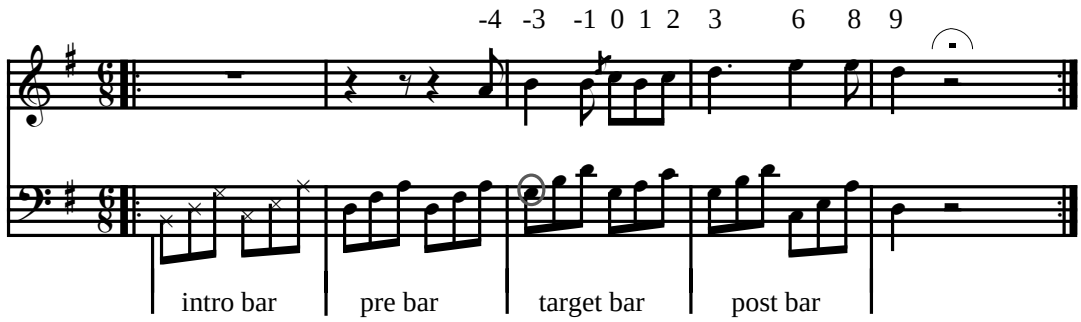


Fig. 1: Score of fragment 1. The annotation indicates boundaries between the introductory bar, the pre bar, target bar and the post bar, and the score times of the melody notes in eighth notes preceding and following the main note. The circled accompaniment note is used as reference note in the grace duration analysis.

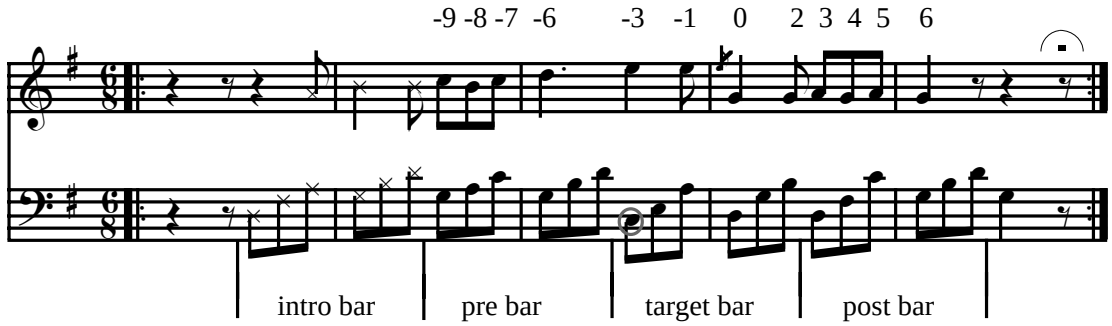


Fig. 2: Score of fragment 2. The annotation indicates boundaries between the introductory bar, the pre bar, target bar and the post bar, and the score times of the melody notes in eighth notes preceding and following the main note. The circled accompaniment note is used as reference note in the grace duration analysis.

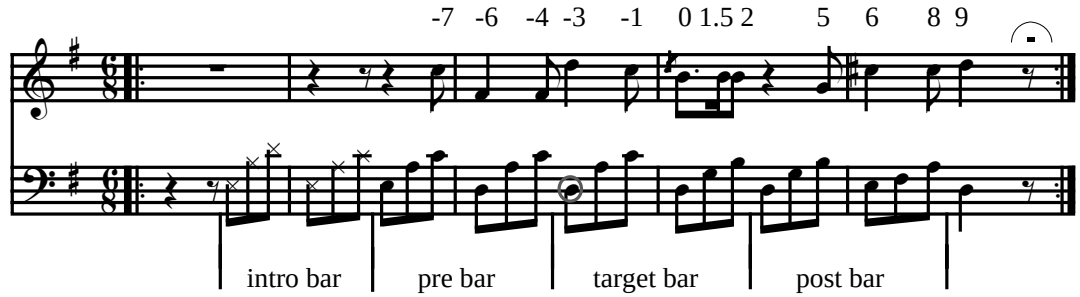


Fig. 3: Score of fragment 3. The annotation indicates boundaries between the introductory bar, the pre bar, target bar and the post bar, and the score times of the melody notes in eighth notes preceding and following the main note. The circled accompaniment note is used as reference note in the grace duration analysis.

These fragments are chosen on the basis that they contain three grace notes that might be expected to be timed differently. Windsor et al. (in press) showed that the size of the melodic intervals before and after a grace note are the best predictors of its duration [for

the duration of grace notes. The grace note in fragment 1 (Grace 1 hereafter) can be classified as preceding and following a stepwise interval. Grace 2 (the grace note of fragment 2) can be classified as preceding a melodic leap and following a unison interval, which means that it suspends the previous note. Grace 3 (the grace note of fragment 3) can be classified as preceding a stepwise interval and following a unison interval. This classification best explained differences in grace note duration in Windsor et al. (in press). In this prior study, grace notes 1 and 3^2 were played with relatively short inter-onset intervals (IOI's were relationally invariant). Grace note 2 was performed with significantly longer IOI's than the other grace notes and was not relationally invariant: at slower local tempi the grace note was performed shorter than would be expected if relational invariance holds.

Terminology and definitions

In the analyses below, we presuppose three grace note types. The first type is the pre-note *Vorschlag* (see figure 4a). This refers to the instances of grace note timing in which the entire grace duration is taken (or 'stolen') from the previous note. So, local tempo and the duration of the subsequent note (to be called main note hereafter) remain unaffected.

The second option is called the on-note *Vorschlag* (see figure 4b): the grace note is performed simultaneously with the accompanying note, it steals time from the main note and leaves the local tempo and the previous note unaffected.

The last type considered is that of the insertion *Vorschlag* (see figure 4c). This grace note inserts time: the durations of the previous and subsequent note are unaffected, but time is added, which causes a local slowing of tempo.

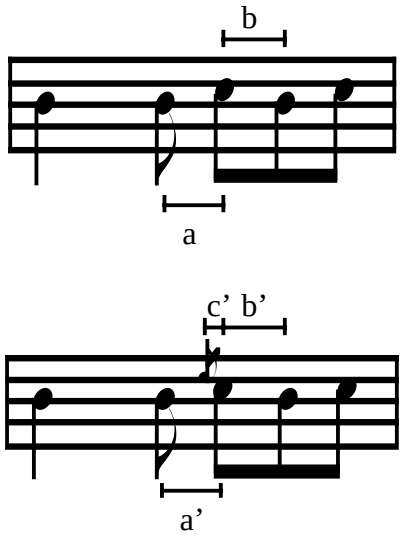


Fig. 4: The melody IOI’s of the ‘without’ and ‘with’ condition used in the analysis of stolen and inserted proportions: ‘without’ previous IOI (a), ‘without’ main IOI (b), ‘with’ previous IOI (a’), ‘with’ main IOI (b’), and grace note IOI (c’).

To differentiate between these grace note types, we make use of three inter-onset-intervals (IOI’s) - the previous IOI (a), the main IOI (b), and the grace note IOI (c) - and measure the stolen and inserted times (see figure 4). Relating the time between the previous onset and the grace note onset to the previous IOI in the ‘without’ condition gives the time stolen from the previous note (see formula 1).

$$p = (a – (a’ – c’)) / c’ \qquad (1)$$

Direct comparison between the main IOI's of two performance conditions – the conditions 'with' grace note and 'without' grace note – gives the time stolen from the main note (see formula 2).

$$m = (b - b') / c' \quad (2)$$

Finally, inserted time is the time added by the grace note insertion to the total duration between previous onset and next onset (see formula 3).

$$i = ((a' + b') - (a + b)) / c' \quad (3)$$

When p, m or i are 1, this means that the time stolen from the previous, main or the time inserted equals the grace note duration, so the entire duration of the grace note stolen from 1 note or inserted. When however they are 0, no time is stolen from that note, or no time is inserted. The three measures are interdependent: they all add up to 1. It is possible for the measures to become negative. For p and m, this means that no time is stolen, but time is added (the previous note or main note are lengthened). For i, this means that time is 'subtracted'; there is less time between the previous note onset and the next note onset in the 'with' condition than in the 'without' condition.

The three types of grace note performance might be interpreted as referring to different strategies: the pianist prefers not to effect local tempo (pre-note and on-note *Vorschlag*), or prefers not to effect the durations of structural notes (insertion *Vorschlag*). When local tempo is not effected, the duration of the grace note is either stolen from the previous note, effecting the previous note offset time (pre-note *Vorschlag*), or from the main note, effecting the main note onset time (on-note *Vorschlag*).

The first two types are related to ornament categories as defined in performance practice literature. The on-note *Vorschlag* refers to the class of *appoggiatura*. The *appoggiatura* proper is a one note ornament that 'leans' on the following, so-called main note (Donington, 2001). It is performed simultaneously with the accompanying note. It is accented and takes half or one third of the time of the main note in case of a long *appoggiatura*, or less than one third of the time of the main note in case of a short *appoggiatura* (Donington, 1989; Neumann, 1986). The pre-note *Vorschlag* refers to a one-note ornament that is performed before the beat. According to Neumann (1986), this is a sensible way of performing *appoggiatura* that precede dotted rhythms in fast tempi, that occur at the start of the piece, before notes of even value, before groups of three even notes, or before staccato notes. Neumann calls this sub-class *grace notes*.

The generality of this last sub-class is debated. For example, according to Donington (1989), it is not allowed to perform *Vorschläge* before the beat. There exist only short and long *appoggiatura* that occur on the beat, simultaneously with the accompanying note. There is one exception to this rule: the passing *appoggiatura* is performed before the beat, in time of the previous note. This passing *appoggiatura* refers to the special case in which a one-note ornament 'fills' a descending third.

The third type (insertion *Vorschlag*) is not mentioned in the literature. Still, we include this as a possibility, since (at least some) time might be inserted when a grace note is added, just as it is possible to lengthen notes or to insert a micro-pause at certain structural positions (see e.g., Sundberg, Friberg, & Frydén, 1991).

Empirical measurements are needed to underpin the existence of clearly separate *Vorschlag* types and to clarify the extent to which the theoretical rules and considerations

return in practice. It might be that it is not possible to separate between interpretations of grace notes as on-note or pre-note *Vorschlag*, but that instead it is a mixture: some time is stolen from the previous, some from the main, and part of the grace duration is additional or inserted time.

Predictions concerning grace type and stolen and inserted times

The prediction is that the grace type interpretation depends on the musical context of the grace note and on the performer's free or strict interpretation of the rule that *appoggiatura* are always performed on the beat and no other types of *Vorschläge* exist (except the passing *appoggiatura*).

Grace 1 is a descending, but not a passing *appoggiatura*: it is a tone above the main note, but does not 'fill' a descending third (see figure 1). Grace 1 is, further, followed by three short notes of equal duration. C.P.E. Bach (1780) mentions this as a context in which the main note cannot be deprived of any part of its value. Interpreting grace 1 as an insertion type would assure that no time is stolen from the main note and that the grace note is not performed in time of the previous note (not performed as a passing *appoggiatura*). According to Neumann (1986), however, a grace note in such a context would most sensibly be performed unaccented: short and before the beat (as our pre-note *Vorschlag*). Donington (1989), in contrast, refers to this context as asking for a short, on the beat interpretation (as our on-note *Vorschlag*).

Grace 2 suspends the previous note and is separated by a melodic leap from the main note (see figure 2). Neumann (1986) refers to this context as a common vocal ornament; the

downward leaping *appoggiatura*. It repeats the preceding pitch, but harmonically belongs to the harmony of the main note. According to Neumann (1986), this downward leaping *appoggiatura* expresses a feeling of warm or tenderness and is considered a long *appoggiatura*. His long appoggiatura equals our on-note type: shortening the main note and performing the ornament simultaneously with the accompanying note.

Grace 3 suspends the previous note and is followed by a dotted rhythm (see figure 3). This dotted rhythm is another instance of a main note that cannot be deprived of any of its value (C.P.E. Bach, 1780). Donington (1989) however makes special mention of the suspension, which can only be a true suspension when performed as a long *appoggiatura*. It is therefore unclear what the most probable interpretation will be on-note interpretation to stress the suspension characteristic of the grace note, or insertion or pre-note *Vorschlag* to not deprive the main note of any of its value.

Table 1 summarizes the predicted grace note interpretations per fragment.

Fragment	Pre-note *Vorschlag*	Insertion *Vorschlag*	Short on-note *Vorschlag*	Long on-note *Vorschlag*
1	+	+	+	
2				+
3	+	+	+	+

Table 1: predicted grace note interpretation for each fragment.

Predictions concerning scaling of grace duration with tempo

We can also propose some hypotheses regarding the way in which the grace notes are performed at different tempi. On the one hand, one might expect relational invariance, as discussed above. On the other hand, there is some evidence to suggest some considerable deviations from relational invariance in musical performance. For example, it has been suggested that local, small scale features may keep their characteristic absolute duration (Repp 1994; Desain & Honing, 1994), rather than maintaining proportional duration. We may infer from these findings that long appoggiatura that take up half or two third of the main note most probably behave as "normal" notes and keep a constant proportion with the duration of the context. Short grace notes are more likely to maintain absolute, rather than proportional duration. This might be especially likely if an ornament relies upon the insertion of a micro-pause. A finding in language that is in line with this prediction is that the time interval between words syllables is found to remain relational invariant with tempo changes, while phonemes are found to keep their duration regardless of tempo (Gentner, 1987).

A different prediction stemming from the performance literature is that *Vorschläge* may end up in different categories when performed in different tempi. For example, a long *appoggiatura* might be most appropriate in a slow and lyrical movement, while short *appoggiatura* are more natural before rapid notes or in a rapid and playful movement (see Neumann, 1986). Such a change in category might disturb the relational invariance of long grace notes and the constant duration of short grace notes.

To summarize, it is hypothesized that shorter ornaments keep constant duration (or scale less than would be expected from relational invariance), while longer ornaments remain a

constant proportion of the sequence duration. This means that grace 1, which is supposedly performed short, has a constant duration irrespective of tempo. In contrast, the duration of grace 2, which is supposedly performed long, is a constant proportion of the sequence duration, while the duration of grace 3 might either be constant (when performed short) or proportional to the sequence duration (when performed long).

To formalize the scaling behavior of ornaments, we assume a linear relation between grace duration and bar-duration. The slope (β in formulae 4 and 5) of this linear relation determines the scaling behavior. To differentiate between relational invariant, constant duration and less (or more) than relational invariant, we need to combine the slopes of two regression analyses. The first provides the slope of the linear relation between grace note duration and bar duration (formula 4).

$$c' = d + \beta * \text{bar IOI} \qquad (4)$$

If this slope is not significantly different from 0, the grace duration is invariant with tempo. If it is greater than 0, the grace duration varies positively with tempo. The second provides the slope of the linear relation between grace note *proportion* and bar duration (formula 5).

$$c'\ \text{prop} = d + \beta * \text{bar IOI} \qquad c'\ \text{prop} = c' / \text{bar IOI} \qquad (5)$$

Grace note proportion is the ratio between grace duration and bar duration. If the slope (B) of formula 5 is not significantly different from 0, the grace note proportion remains constant with varying bar duration, which means that the grace note scales relationally invariant. If the slope is smaller than 0, the grace note scales less than proportionally with bar duration (the grace note proportion decreases with increasing bar duration). If the

slope is larger than 0, the grace note scales more than proportionally with bar duration (grace proportion increases).

Experimental design

The experiment has three conditions: tempo, presence and musical fragment. The tempo condition has seven levels (45, 50, 55, 60, 65, 70, and 75 BPM). The presence condition has two levels (‘with’ and ‘without’). And the fragment condition has three levels (the three fragments shown in figures 1-3). In addition, each subject repeated each performance in each condition eight times. These repetitions are not considered as a factor in the analyses. Instead, averaged data is used (averaged over repetitions).

The order of the tempi was randomized for each subject. The order of the presence conditions was counter-balanced between subjects: subjects 1-8 first performed the fragments without a grace note and then performed the fragments with the grace note, while subjects 9-16 were first given the with grace note musical fragments and then the without grace note musical fragments. The order of the three musical fragments was fixed and followed the order of presentation of the original theme.

Pianists

Sixteen professional pianists participated in the experiment. They were all highly trained pianists with considerable experience in performance and teaching. The Beethoven piece was familiar to all of them. The pianists were paid for their participation.

Procedure

The score of the Beethoven theme was sent to the pianists two weeks before the experimental session. The pianists were asked to practice the piece at home in seven different tempi (ranging from 45-75 BPM), both with and without grace notes.

In the experiment, the pianists did not perform the original Beethoven theme, but were given the six musical stimuli, and asked to play them eight times at each of the seven tempi. First, however, the pianist was given time to get acquainted with grand piano. He was then instructed that for each fragment he would hear a metronome indicating the tempo over speakers, a synthetic piano performing the introductory measure (intro bar, figures 1-3), where after he should continue to perform the remaining measures. After a pause of variable length, the synthetic piano would sound again and the pianist was expected to perform the remaining measures. This was repeated 8 times.

The pianists were also instructed to follow the tempo indicated by the metronome and the mechanical introduction, but simultaneously to perform the fragment as musically and expressively as possible, to perform each repeat of a fragment with the same expression and interpretation, not use any pedaling and to continue even if they made an error. The recording session was then started and lasted around one and a half hours, including two or three short breaks.

During the recording session, the experimenter kept track of ‘good’ and ‘bad’ repetitions. A repetition was considered ‘bad’ when it contained an obvious mistake (forgetting to start performing after the introduction had sounded). At the end of the session a few short

questions regarding the experiment and their interpretation of the ornaments were asked of the participants.

Data collection

The pianists performed on a Yamaha MIDI grand piano from which MIDI information was sent to a Macintosh G4 running Opcode VISION DSP 4.2.2c. A metronome sound and synthetic piano sound were played back using a Yamaha MU90 synthesizer, while the grand piano MIDI information was recorded. The metronome and intro bar were constructed in POCO (Honing, 1990) as a MIDI file. The recordings were processed in POCO to remove everything except note information. They were then matched to a nominally isochronous score allowing for analysis of expressive timing (Heijink, Desain, Honing, & Windsor, 2000).

Repetitions containing some serious mistake were left out of the analysis. Repetitions were also omitted when one of the following crucial notes for the analyses was missing:

1) the grace note
2) the main note of the melody and the accompaniment
3) the previous and the next note of the melody.

This sorting of repetitions led to the elimination of 1.6% of the total of repetitions across all subjects. Generally, this sorting caused the elimination of 1 or maximally 2 of the 8 repetitions of each tempo, fragment and grace-note presence condition. There was, however, one exception: in the interpretation of subject 14 (S14), the grace note of

fragment 3 substitutes the main note. In other words, S14 performed the ‘with’ grace note condition of fragment 3 with a grace note that is as long as the main note in the ‘without’ condition and that has the same onset time as the main note in the ‘without’ condition. This exceptional case of grace note performance is not present in the analyses.

Results

Instructed vs. realized tempo

Two checks of tempo adherence should be made to ascertain the reliability of the results of the analyses of stolen times and scaling behavior. The first check concerns the consistency of tempo between ‘with’ and ‘without’ grace note conditions. The second check concerns the obedience of the pianists to the instructed tempo as indicated by the metronome and the computer introduction.

The first check concerns the consistency of tempo between ‘with’ and ‘without’ condition. This consistency is important since the stolen and insertion time measurements are based on a direct comparison of onset times between ‘with’ and ‘without’ condition. Global or local tempo differences between these two conditions that are not directly due to the presence of the grace note, but are more an effect of order, fatigue or otherwise, would effect the stolen time measurements in uncontrolled manner.

We take the pre bar IOI (the first bar performed by the pianists, see figure 1-3) as dependent variable, since the start of each fragment should have similar duration in the ‘with’ and ‘without’ conditions. In a repeated measures MANOVA, the effect was tested of intro bar IOI (taken as nominal variable with three levels), fragment, presence and all

interactions between them on the pre bar IOI. The main effects of intro bar IOI and fragment were significant, as well as the interaction between fragment and intro bar IOI (see table 2). There was no main effect of presence, nor were there significant interactions between presence and intro bar IOI, presence and fragment, or between presence, intro bar IOI and fragment (see table 2).

In other words, there are no consistent effects of grace note presence, nor are there any interactions with presence found. This means that within each instructed tempo category the mean tempo of the pre bar is the same for the 'with' and the 'without' condition.

Dependent variable: pre bar IOI

Independent variable		
Intro bar	F (6,84) = 1342.28	$p < .0001$
Fragment	F (2,28) = 26.85	$p < .0001$
Presence	F (1,14) = .13	$p > .1$
Intro bar * presence	F (6,84) = 1.22	$p > .1$
Intro bar * fragment	F (12,168) = 6.43	$p <.0001$
Presence * fragment	F (2,28) = 1.22	$p > .1$
Intro bar * presence * fragment	F (12,168) = 1.30	$p > .1$

Table 2: Results of a repeated measures MANOVA with intro bar (7 levels), fragment (3 levels), presence (2 levels) and their interactions as independent variable and pre bar IOI as dependent variable. There is no significant effect of or interaction with presence.

The second check concerns the adherence of the pianists to the instructed tempo as indicated by the metronome and the computer introduction. This is especially important for the grace note duration scaling analysis, because in this analysis a linear relation between the tempo conditions is assumed.

Figure 5 shows the relation between the intro bar IOI (which equals the duration of a bar in mechanical tempo) and the realized pre bar IOI. An ideal realization of instructed tempo would predict a perfect proportional relationship (a slope of 1). Instead the relation between realized and intro bar IOI shows a slope of 0.87; there is a tendency for the pianists to perform the higher tempi a bit slower than instructed and the lower tempi a bit faster than instructed[3].

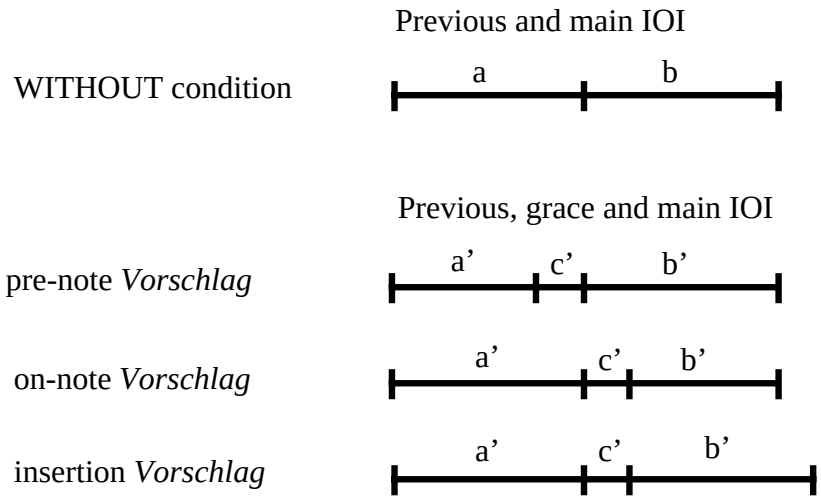
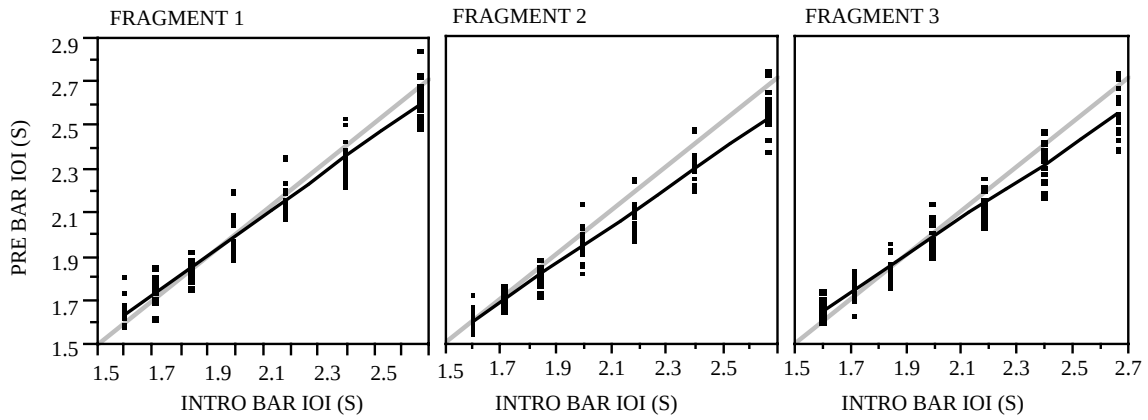


Fig. 5: Three types of grace note interpretation: pre-note Vorschlag (grace note is performed in time of the previous note), on-note Vorschlag (grace note is performed in time of the main note), and insertion Vorschlag (grace note does not steal time, but shifts the main note ahead). a is previous IOI; b is main IOI; c' is grace note IOI.

Though the experiment has provided a wide range of realized tempi and tempo adherence can be undoubtedly said to be high, still the intro bar IOI does not exactly represent the average pre bar IOI within each tempo category. This means that when we would analyze the scaling behavior of the grace note IOI vs. the intro bar IOI, we would bias the analyses towards less than relational invariant scaling.



FRAGMENT 1: pre bar IOI = 0.19 + 0.90 intro bar IOI
FRAGMENT 2: pre bar IOI = 0.20 + 0.87 intro bar IOI
FRAGMENT 3: pre bar IOI = 0.30 + 0.84 intro bar IOI

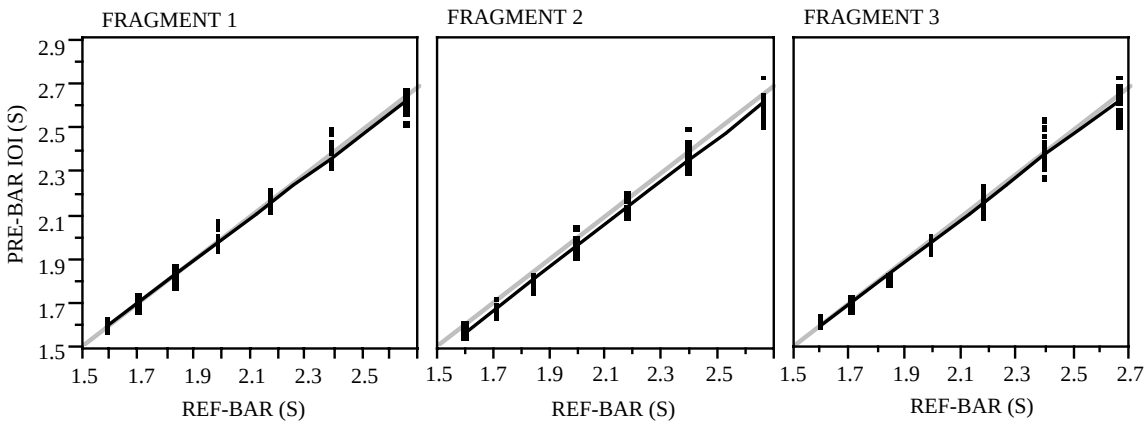
Fig. 6: The realized pre bar IOI is plotted against the instructed bar duration: the intro bar IOI. Individual values are plotted and a line is fitted through these values (black line). The gray line indicates a perfect proportional relationship between pre bar IOI and intro bar IOI. The details of the line fit are given below the graph. The slope for all three fragments is smaller than 1.

A solution to this problem is provided by using a measure of realized tempi as independent variable, i.e., a regrouping of the performances into tempo-categories that are in closer agreement with the realized tempi. In this way, the tempo category 45 BPM (reference bar IOI of 2.67 S) will only contain performances with a pre bar tempo

between 42.5 and 47.5 (pre bar IOI between 2.82 and 2.53 S). The tempo category of 50 BPM will only contain performances with pre bar tempi between 47.5 and 52.5, etc. In other words, the performances are organized in groups of performances that have similar pre bar tempi. This organization is closely related to the organization in instructed tempi. Only when the realized pre bar IOI falls outside the group boundaries of the instructed bar IOI is the performance regrouped into the reference bar category that does fit the realized tempo. Figure 6 shows that, after this reorganization, the reference bar IOI represents the distribution of realized (pre bar) tempi well – the slope is close to 1.

Effect of grace presence

The first effect of interest is the position of the grace note and any time shift that causes to the timing of the surrounding notes. Figure 7 shows that consistent differences between the local tempo patterns of the melody of the 'with' and 'without' condition only occur around the grace note, which is located somewhere between score time –1 (previous note) and 0 (main note, see figures 1-3). For grace 1 and 2, the only difference between the conditions concerns the local tempo of previous and the main note (score times –1 and 0, respectively). For grace 3, there is hardly any change in local tempo at all. There are only some occasional differences: In faster tempi, the previous note (score time –1) is slower in the 'with' condition, while the first note of the target bar (score time –3) is slightly faster. At slower tempi, the next note (score time 1.5) is faster in the 'with' condition[4].



FRAGMENT 1: pre-bar-IOI = 0.05 + 0.96 ref-bar-IOI
FRAGMENT 2: pre-bar-IOI = -0.02 + 0.99 ref-bar-IOI
FRAGMENT 3: pre-bar-IOI = 0.02 + 0.98 ref-bar-IOI

Fig. 7: This figure is as figure 5, only the pre bar IOI's are plotted against their reference bar IOI, which is the instructed category closest to the realized pre bar IOI. The slope of the line fits are close to 1.

Additionally, we saw that there was no consistent effect of grace note presence on the pre bar IOI of the accompaniment. A similar repeated measures MANOVA was conducted to test the effect of fragment, tempo category, and the interaction of fragment and tempo category on the target bar IOI of the accompaniment. This test showed no significant main effect of presence. It did show a significant interaction between presence and fragment. This interaction indicated a generally faster 'with' condition than 'without' condition for fragments 1 and 3, but an equally fast 'with' and 'without' condition for fragment 2. The same MANOVA was conducted with the post bar IOI of the accompaniment as dependent variable. This analysis showed no significant main effect of presence and no significant interaction between fragment and presence.

To summarize, all systematic effects of grace presence on the timing of structural notes seem local and restricted to the target bar. Interestingly, the only effect of grace note presence found that extend over the direct neighbors is a faster target bar in the 'with' condition than in the 'without' condition of fragment 1 and 3. In these fragments, rather than adding a pause or delay in which the pianists can play the ornament and otherwise maintaining the tempo (which would lead to a greater bar duration), the surrounding notes are played faster, shortening the duration of the bar despite the addition of an extra melody note.

Grace note position

Figure 8 shows the average onset times of the grace note, main melody note and next melody note, plotted against the onset time of the previous melody note (y = 0). Gray lines indicate the relative onset times of the 'without' condition, while black lines show onset data for the 'with' condition. The dotted lines indicate the position of successive eighth notes when they would have been performed in the instructed tempo. The data are averaged over performers.

It can be seen that, for all grace notes, the grace onset occurs before the melody main note onset of the 'without' condition. It can also be seen that for grace 1 and 3 the relative melody main note onsets are roughly the same for the 'with' and the 'without' conditions (the two lines are superimposed). For grace 2, however, the melody main note of the 'with' condition is relatively later than the melody main note in the 'without' condition.

The next melody notes of the ‘with’ and ‘without’ condition are roughly simultaneous for all three grace notes.

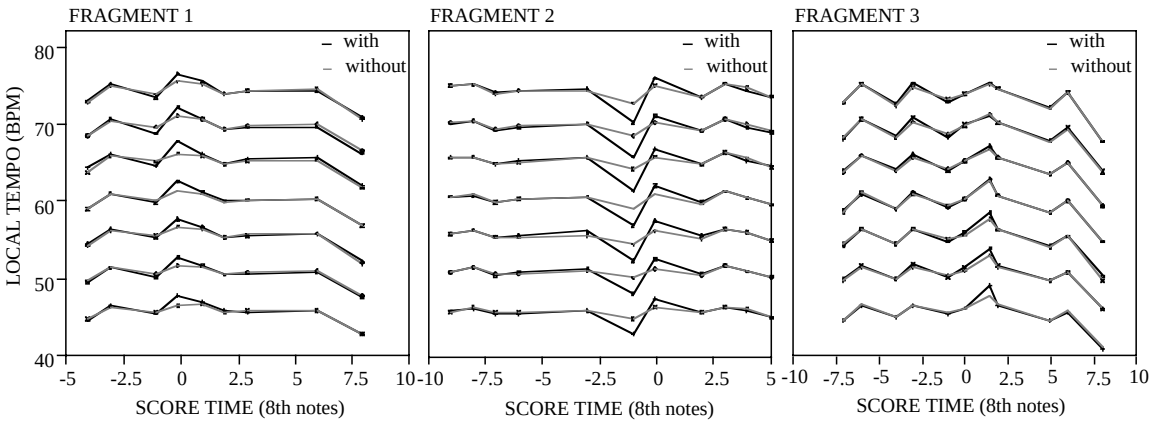


Fig. 8: Local tempo is indicated per melody note. Plots are separated for the three fragments, separate lines indicate local tempo of ‘with’ and ‘without’ condition. The score times of the melody note are given below. Score time 0 refers to the onset of the main note; negative score times indicate the position of note in eighth notes preceding the main note onset; positive score times indicate the position of note in eighth notes following the main note onset.

These differences in relative onset timing are captured by the proposed stolen and inserted durations (see formulae 1-3). The stolen and inserted durations also indicate the position of the grace note, since the previous stolen proportion corresponds to the grace onset, while the main stolen proportion corresponds to the grace offset.

To shortly repeat the definitions: The duration that the grace note is performed before the main note of the ‘without’ condition is the time stolen from the previous IOI. The difference in duration between main IOI of the ‘with’ and ‘without’ condition is the time

stolen from the main IOI. And, the difference in onset time of the next note is the inserted time. Though this difference is not an absolute difference, but relative difference, since the onset times of the previous notes are aligned. Stolen and inserted times are given as proportions of the grace note duration, since this provides the opportunity to generalize over graces with different durations that are due to between subject differences or global tempo differences.

Three MANOVA's test the effect of fragment, tempo category and the interaction between fragment and tempo category on insertion proportion, main stolen proportion and previous stolen proportion, respectively. When significant differences are shown to exist between the grace notes of the three fragments, we conduct separate analyses for each fragment that test the hypotheses that different *Vorschläge* are characterized by either a previous stolen proportion of 1 (pre-note *Vorschlag*), a main stolen proportion of 1 (on-note *Vorschlag*), or an insertion proportion of 1 (insertion *Vorschlag*) with the other proportions being equal to 0. We test these hypotheses with separate t-tests. Three t-tests test the difference of the previous stolen proportion, the main stolen proportion and the insertion proportion from 0. And three t-tests test their difference from 1.

The results of the three MANOVA's are shown in table 3. The results of the separate t-tests are reported in the text below. Table 4 summarizes the stolen time characteristics of each grace note as found in the analyses.

	p	m	i
Fragment	F (2, 26) =8.73 p <.001	F (2,26) = 1.39 p > .1	F (2,26) = 6.85 p < .005
Tempo category	F (6, 78) = 3.09 p < .01	F (6,78) = 1.74 p > .1	F (6,78) =7.95 p < .0001
Fragment * tempo category	F (12, 156) = 1.21 p > .1	F (12,156) = 1.35 p > .1	F (12,156) = 6.85 p < .005

Table 3: Results of three repeated measures MANOVA's with fragment (3 levels), tempo category (7 levels) and their interaction as independent variable and previous stolen proportion (p) or main stolen proportion (m) or insertion proportion (i) as dependent variable.

	Fragment 1	Fragment 2	Fragment 3
p	Mean = .96 .96 = 1	Mean = .68 0 < .68 < 1	Mean = .92 .92 = 1
m	Mean = .20 0 < .20 < 1		
i	Mean = -.18 -.18 < 0 < 1	Mean = .0647 0 < .0647 < 1	Mean = .0140 = 0

Table 4: Mean previous stolen proportions, mean main stolen proportion and mean insertion proportion. Averages are split per fragment when a significant effect of fragment was found in the MANOVA. Per mean is indicated its significant difference from 0 and 1 based on results of the t-tests.

Previous stolen proportion

The third repeated measures MANOVA reported in table 3 shows significant main effects of fragment and tempo category on the previous stolen proportion. There is no significant interaction between fragment and tempo category. However, there are significant between subject effects. The effect of fragment is such that on average the proportional duration stolen from the previous note is larger for grace 1 and 3 than for grace 2.

When we examine the previous stolen proportions separately with the aid of a t-test, we find that the previous stolen proportion equals 1 for grace 1 and 3 ($t(15) = -.45$, $p > .5$ and $t(14) = -1.93$, $p > .5$ respectively) and is greater than 0 but smaller than 1 for grace 2 ($t(15) = 6.32$, $p < .0001$ and $t(15) = -3.03$, $p < .01$ respectively).

The effect of tempo category is such that higher tempi have smaller previous insertion proportions than lower tempi (see figure 9). This result is best understood in relation to the positive insertion proportion at higher tempi: most of the *Vorschläge* are performed by subtracting duration from the preceding melody note, but at higher tempi some time is inserted as well**.** An interpretation of this result might be that at lower tempi, there is more room for the grace note, so there is less need to insert time.

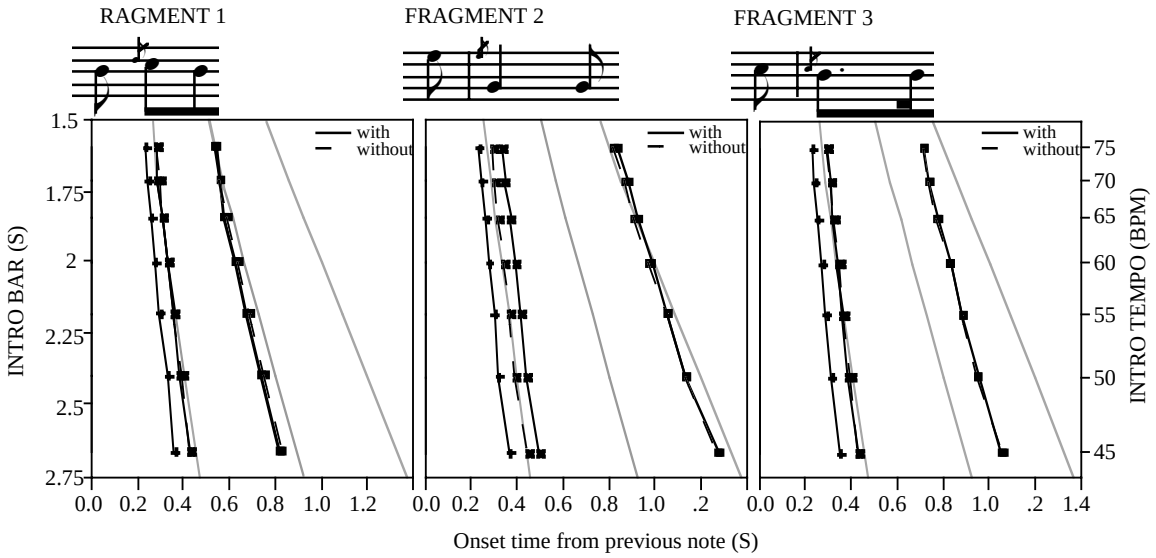


Fig. 9: Black lines from left to right: Onset time of grace note, main note and next note in respect to the previous note onset. Gray lines indicate the onset times of the eighth notes in a mechanical tempo. Onset times are given for the seven tempi of the experiment.

Main stolen proportion

The repeated measures MANOVA (see table 3) showed no main effects of grace type, tempo category and no interaction between fragment and tempo category on the duration stolen from the main note.

On average, the main stolen proportion is significantly larger than 0 and smaller than 1 ($t(15) = 2.94$, $p < .05$ and $t(15) = -11.55$, $p < .001$ respectively). It has a mean of 0.20.

Insertion proportion

There are significant main effects of fragment and tempo category and a significant interaction between these factors on the insertion proportion. These main effects and interactions show that the amount of inserted time differs between fragments and between tempo categories, and that the effect of tempo category is not the same for all fragments.

The separate analyses for each fragment show that the insertion proportion of fragment 1 is significantly smaller than zero ($t(15) = -3.49$, $p < .005$). The insertion proportions of fragment 2 and fragment 3 are not significantly different from zero ($t(15) = .065$, $p > .1$ and $t(14) = .27$, $p > .1$, respectively).

The negative insertion proportion of fragment 1 is in contrast with the expectation that the insertion of an extra note (an ornament) adds or inserts time, but is in line with the finding of a faster target bar in the 'with' condition than in the 'without' condition. Surprisingly, the negative insertion proportion is not found for fragment 3, which also showed a faster target bar in the 'with' condition than the 'without' condition. Apparently, the difference in target bar IOI is only due to shorter notes at the start or end of the target bar of fragment 3. In figure 7, we already saw that especially in slower tempi, the but-last note is faster in the 'with' condition of fragment 3 than in the 'without' condition. In faster tempi, there is a trend for the first note of the target bar (score time –3) to be slightly faster in the 'with' condition, which could also contribute to the generally faster tempo of the target bar in the 'with' condition as opposed to the 'without' condition.

The main effect of tempo category on insertion proportion is such that lower tempi tend to show a negative insertion proportion, while the higher tempi show no or a positive insertion proportion.

The interaction between tempi and fragments specifies this observation by indicating that fragment 1 shows negative insertion proportions for all tempi, and fragments 2 and 3, on the other hand, show at lower tempi little or no negative insertion proportions, and at higher tempi they show positive insertion proportions. Figure 10 shows the details of this interaction between the tempo category and fragment effects on the insertion proportion.

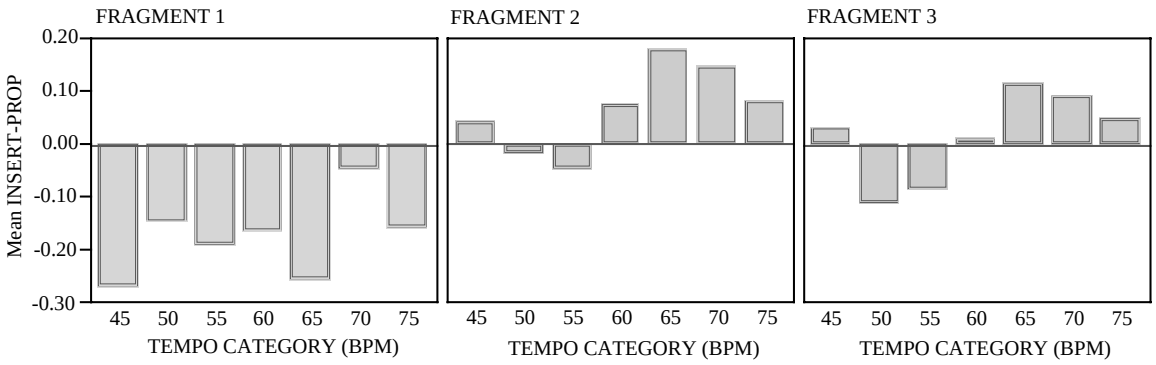


Fig. 10: Mean insertion proportion per tempo category. Plots are not separated per fragment, since no significant effect of fragment was found in the MANOVA.

Subject effects

The previous analyses describe the position and magnitude of the stolen and inserted durations for the three fragments. Overall, the grace notes were performed as pre-note

Vorschläge: with all their time stolen from the previous note and from the main note. We did not find consistent on-note or insertion *Vorschlag* interpretations.

Table 5 shows for each fragment the number of subjects that show certain characteristic combinations of main and previous stolen proportions. The insertion proportions are not reported, since they are apparent from the other two stolen proportions.

It can be seen that there are more and different combinations than the three predicted grace note types. This is due to the fact that the combinations reported are data driven, while the predicted types were theory driven. The option of insertion *Vorschlag* is not present in the table (p = 0 & m = 0), since there were no subjects who showed such interpretation. The options of pre-note and on-note *Vorschlag* are implicitly present, only not as neatly as predicted. Below, we will continue on this issue.

		Fragment 1		Fragment 2		Fragment 3	
		# of subjects	mean	# of subjects	mean	# of subjects	mean
1	m =< 0 p => 1	9	.02 1.14	3	.04 1.15	8	.06 1.01
2	m =< 0 0 < p < 1			3	.05 .55	6	.06 .78
3	0 < m < 1 p => 1	4	.33 .92	3	.21 .97	1	.18 .97

4	0 < m < 1 0 < p < 1	2	.41 .72	4	.16 .72		
5	0 < m < 1 p = 0			2	0.72 0.03		
6	m => 1 p = 0	1	1.093 .06	1	1.18 -.12		

Table 5: Number of subjects who show certain combinations of stolen proportions from the main (m) and the previous note (p) are indicated per fragment. Mean stolen proportions are given per subject group of each fragment.

Table 5 shows that for all three fragments the majority of performances fall within the first three categories in which no time is stolen from the main note and/or all time is stolen from the previous note. For grace 3, all performances (except those of S14 who is not represented in this table) fall within these three categories.

The majority of performances of grace 1 and 3 even falls in the first category (m =< 0 & p => 1) in which no time is stolen from the main and all time is stolen from the previous. In addition to this, there are subjects who perform grace 1 and 3 with most time stolen from the previous note and some inserted time or some time stolen from the main note. An exception to this is S14 who performs the graces with all time stolen from the main and no time stolen from the previous (category 6).

Grace 2 shows a much more diverse picture of interpretations. Still, most performances steal most time from the previous and only some or no time from the main. But, the mean time stolen from the previous is less than for grace 1 and 3. Within the first four

categories, the mean time stolen from the main is roughly the same as for grace 1, since the high stolen proportions from the main and previous for grace 1 are distorted by the faster tempo of the target bar of the 'with' condition.

Grace 2 specifically shows a larger number of subjects who steal both time from the previous and the main (4 subjects) and three subjects who steal no time from the previous at all. Subject 14 is the only subject, among these three subjects, who steals all time from the main and no time from the previous.

Generally, only a little time is inserted, and the insertion proportion is always much smaller than 1.

Interpretation

Generally, all three fragments showed pre-note *Vorschlag* interpretation: most to all time stolen from the previous note, little to no time stolen from the main note and no time or negative time inserted. Though this interpretation does not fully agree with the prototypical pre-note *Vorschlag* performance that predicts a previous stolen proportion of 1 and a main stolen proportion and insertion proportion of 0, grace 1 and 3 are in close agreement with this prototypical description.

Grace 1 deviates from the prototypical description by showing negative insertion proportion and positive main stolen proportion. Both can be attributed to the faster tempo of the target bar in the 'with' condition.

Grace 2 deviates from the prototypical description by showing a previous stolen proportion that is smaller than 1, and a main stolen proportion that is larger than 0, which

would make grace 2 an “in between case”. The proportion stolen from the previous note is, however, considerably larger (more than twice as large) than the proportion stolen from the main note, which makes fragment 2 closer to a pre-note interpretation than to an on-note interpretation.

The performance of the grace notes appeared to be only partly determined by the musical context. Specific interpretation by the performer seems of equal importance. For example, half of the subjects interpret fragment 2 as a pre-note *Vorschlag*: all time stolen from the previous and/or no time stolen from the main. Four subjects interpreted fragment 2 as an “in between” case and three subjects performed fragment 2 as an on-note *Vorschlag*. The “in between” case is still much closer to a pre-note interpretation than an on-note interpretation. The on-note interpretation clearly differs from the other interpretations by showing a previous stolen proportion of zero and a main stolen proportion equal or close to one.

Grace duration

In the following analyses, grace duration is defined as the time interval between the onset of the grace note and the onset of the main melody note. We assume a linear relationship between grace and bar duration (see figure 11, which shows that this is reasonable). The slope of this line shows whether the grace remains relationally invariant to the bar duration, whether it keeps a constant duration, or whether it scales more or less than proportionally.

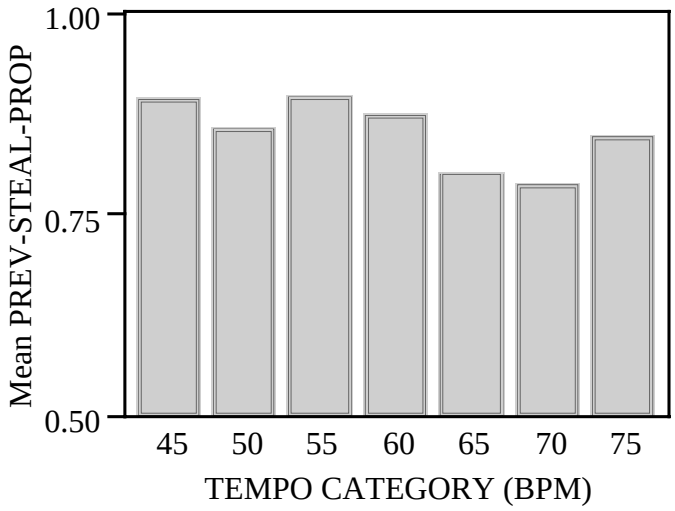


Fig. 11: Mean insertion proportion per tempo category. Plots are separated for the three fragments.

In this analysis, the durations of the grace notes are compared with selected eighth notes from each fragment, over tempi. The comparison notes are the first accompaniment note (g of the G major chord) of the third measure of the first fragment (figure 1), and the fourth accompaniment note of the third measure of the second and third fragments (c of the a minor chord and d of the D7 chord, figure 2 and 3, respectively). These accompaniment notes are chosen to provide a fair impression of the scaling behavior of structural notes. We assume that this fair impression is guaranteed, since the notes do not fall within the pre bar, which would make them more likely to scale proportionally with tempo (since they are close to the mechanical introduction). Neither are they in the direct neighborhood of the grace note (and therefore their timing is not likely to be affected by the grace note presence), or part of the final ritard that in most cases occurred the last measure of the fragments. In addition, these accompaniment notes were chosen because they have duration that is close to that of the grace notes.

A repeated measures MANOVA tested the effect of note type (grace note or eighth note), fragment (three levels), bar duration (continuous variable), and their interactions on the (grace or eight) duration.

A second repeated measures MANOVA tested the same effects on (grace or eighth) proportion**.** The reference bar IOI that corresponds to the duration category of the pre bar IOI is taken as bar duration measure (see section on *Instructed vs. realized tempo*). Grace proportion is defined as grace duration expressed as a fraction of the reference eighth note IOI. The reference eighth note IOI is the reference bar IOI divided by six (since there are six eighth notes in one bar). Eighth proportion is the fraction between eighth note IOI and reference bar IOI. The fastest duration-category of 1.6 S had to be omitted from the analyses, since too few data points fell within its duration range. The results of the two MANOVA's together make it possible to differentiate between invariant relational, invariant and more or less than relational invariant scaling behavior.

	Note duration		Note proportion	
Note type	F (1,14) = 3351.18	$p < .001$	F (1,14) = 53.19	$p < .001$
Fragment	F (2, 28) = 19.70	$p < .001$	F (2, 28) = 42.13	$p < .001$
Context duration	t (15) = 26.12	$p < .001$	t (15) = -3.98	$p < .005$
Type * context duration	F (1,14) = 2041.21	$p < .001$	F (1,14) = 38.98	$p < .001$
Type * fragment	F (2,28) = 50.87	$p < .001$	F (2, 28) = 46.55	$p < .001$
Fragment * context duration	F (2,28) = 4.72	$p < .05$	F (2,28) = 1.02	$p > .1$

Type * fragment * context duration	F (2,28) = 3.99	$p < .05$	F (2,28) = 1.87	$p > .1$

Table 6: Results of two repeated measures MANOVA's with either note duration or note proportion as dependent variable and note type (2 levels), fragment (3 levels), and context-duration (continuous variable) as independent variables.

The results show significant main effects of note type, fragment and context duration on both duration and grace proportion (see table 6). These effects refer to a general trend in which eighth notes are considerably longer than grace notes, the average duration of graces and eighth notes is larger in fragment 2 than in the other fragments, and both note types tend to scale less than proportionally with tempo, although still following a linear relationship (although see the interaction below).

More importantly the results show significant interactions between note type and context duration and between note type and fragment. The interaction between note type and fragment refers to the difference in relative duration of the grace notes and the eighth notes in the three fragments. Grace 2 is longer than grace 3, which is longer than grace 1. Eighth note 1 is longer than eighth note 3, which is longer than eighth note 2. The relative differences between the eighth notes are much smaller than of the grace notes. The shortest eighth note (eighth note 2) has still 95% of the duration of the longest eighth note (eighth note 1). The shortest grace note has however half the length of the longest grace note (see table 7).

The interaction between note type and context duration implies that the slope of the scaling is different for eighth notes and grace notes**.** Examination of the means shows that

in general the grace notes scale less than proportionally, while eighth notes scale more than proportionally.

There is a significant interaction between note type, fragment and context duration for the duration measures, but not for the proportion measures. Table 7 shows the details of this effect: the duration of grace 2 increases more with context duration than the duration of grace 1 and 3**.** However**,** when corrected for mean grace duration, all three grace notes vary in the same way**.** The rationale behind this correction is that longer durations should increase more per unit of context duration than shorter ones. There are no significant differences between the scaling behavior of the different eighth notes.

Fragment	Grace duration		Grace proportion		Eighth duration		Eighth proportion	
	mean (S)	β1	mean	β2	mean (S)	β1	mean	β2
1	.062	.018	.183		.333 S		.161	
2	.113	.038	.338	}-.044	.316 S	}.165	.155	}.003
3	.076	.024	.224		.321 S		.157	

Table 7: Note IOI at tempo 60 (reference bar IOI 2) and mean slope (β) of relation between note IOI and reference bar IOI. Averages are split per fragment when a significant effect of fragment was found in the MANOVA. All mean slopes (β1, β2) are significantly different from 0 ($p < .01$).

When we turn to individual subjects, it becomes clear that the average non-proportional scaling behavior is a compound effect in which the two extreme cases of relationally invariant and invariant scaling of grace duration with context duration do occur. Table 8

shows that for each grace note there are subjects who perform the grace note with constant duration as well as subjects who perform the grace note with relationally invariant duration. There is an interesting preference for grace 1 to be performed with constant duration (56% of the subjects) in contrast to the other two graces, which mainly show less than proportional behavior. There is also a small number of subjects who consistently perform the grace notes with relationally invariant (S3 and S9) or with constant duration (S2 and S4). S14 performed the grace notes with more than relational invariant scaling as in the case of the eighth notes. The duration of the grace notes in her performances is considerably longer than in any other performance.

Scaling behavior of grace note	Fragment 1		Fragment 2		Fragment 3	
	# of subjects	mean c' (S)	# of subjects	mean IOI (S)	# of subjects	mean c' (S)
$\beta1 = 0, \beta2 < 0$	9	.050	3	.109	2	.056
$\beta1 > 0, \beta2 < 0$	1	.090	6	.121	9	.089
$\beta1 > 0, \beta2 = 0$	5	.061	6	.103	4	.059
$\beta1 > 0, \beta2 > 0$	1	.134	1	.140		

Table 8: Number of subjects performing the grace notes with constant ($\beta1 = 0, \beta2 < 0$), less than relationally invariant ($\beta1 > 0, \beta2 < 0$), relationally invariant ($\beta1 > 0, \beta2 = 0$) or more than relationally invariant ($\beta1 > 0, \beta2 > 0$) duration in respect to bar duration. Mean grace note IOI (c') per subject group.

Interpretation

To summarize, the ornamental notes are different from eighth notes in two respects: first, they are significantly shorter than eighth notes and secondly, they show different scaling behavior. The duration of the grace notes was even less than a sixteenth note, since the grace proportion was smaller than 0.5. All three grace notes scale less than would be expected given relational invariance with context duration, whilst the three eighth notes were found to scale more than would be expected given relational invariance.

In confirmation of Windsor et al. (in press), grace 2 was performed longer than grace notes 1 and 3.

The scaling behavior of the grace notes differs considerably between subjects. Instances were found of both invariant as well as relational invariant grace note duration scaling. For one subject (S14), the scaling behavior of the eighth notes and grace note did not differ: both scaled more than proportionally with tempo.

In other words, the scaling behavior of grace notes was not bound to fragments, but nor was it clearly bound to ornament categories. The subjects that were shown in the stolen time analyses to interpret the ornaments as grace notes showed constant duration, relationally invariant or less than relationally invariant scaling. The subjects that were shown to interpret grace 2 as an on-note *Vorschlag* were not the only ones that performed grace 2 with relationally invariant duration.

Accompaniment

While we now have a fairly precise idea about the position of the grace note relative to the "nominal" position of the melody notes, we do not yet know how the accompaniment notes might be affected by the insertion of an ornament. One might expect the main accompaniment note (the note in the left hand which is nominally isochronous with the main note) to be isochronous with the main note, regardless of whether the grace note is present, or to occur at the same time as the grace note in the 'with' condition and the main note in the 'without' condition, or at some intermediate position.

To differentiate between these hypotheses, we use the same IOI's as above: a, a', and c', plus a new IOI one that refers to the accompaniment 'with' condition: A' (see figure 12). Two formulae can now be used to describe the relationship between the three notes:

k = a' – A'

l = a' – c' – A'

If k is zero, melody and accompaniment are performed roughly simultaneous (despite some asynchrony that is present at the previous note and the main note, which is 11ms in fragment 1, and 16ms in fragments 2 and 3[5]). If k is larger than zero, the accompaniment comes relative early (A' is shorter than a'); when it is smaller than zero, the accompaniment comes relatively late (A' is larger than a'). If l is zero, the accompaniment is performed roughly simultaneous with the grace note (A' is equal to a' – c'). If it is larger than zero, the accompaniment is performed roughly before the grace note (A' is smaller than a' - c'), when it is smaller than zero, the accompaniment is performed roughly after the grace note (A' is larger than a' – c').

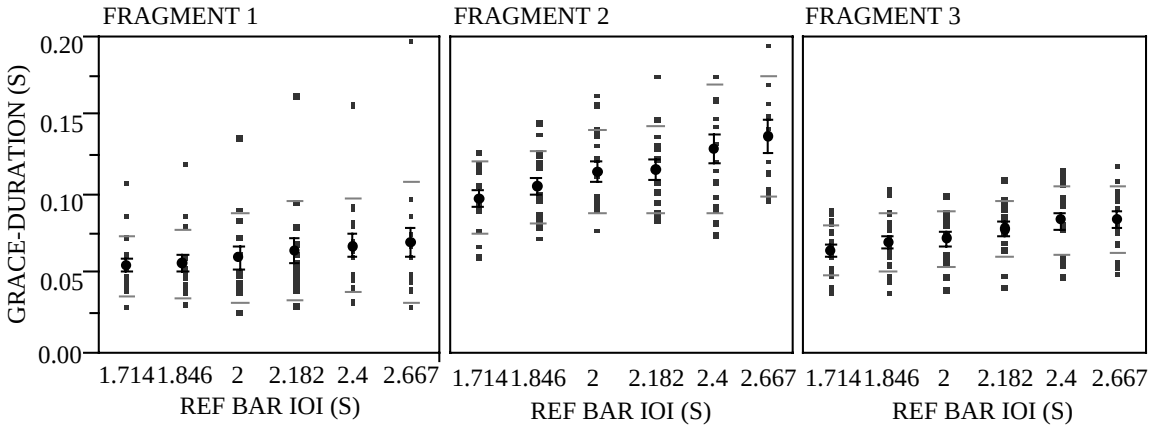


Fig. 12: Individual values and mean values of grace note duration per reference bar IOI category. The average values increase systematically and roughly linearly with reference bar IOI.

Two repeated measures MANOVA's with k or l as dependent variable and tempo (7 levels) and fragment (3 levels) as independent variables were conducted to test the effect of tempo and fragment on the relative position of the accompaniment. No significant main effects or interactions were found.

In table 9, the data is split for different characteristic asynchronies between melody main onset or grace onset and accompaniment main onset. The table shows that the previous IOI of the accompaniment is most often (37.5% of the cases) performed with intermediate length: shorter than the previous IOI of the melody, but longer than the time interval between previous melody onset and grace onset ($k > 0$, $l < 0$). In equally many instances (35.4% of the cases), the previous IOI of the accompaniment is as large as the melody previous IOI ($k = 0$, $l < 0$). In a minority of instances (14.6%), the accompaniment previous IOI becomes as short as the time interval between previous melody onset and grace onset ($k > 0$, $l = 0$). The fourth category in which the

accompaniment previous IOI is shorter than both measured melody IOI's is interesting in the sense that it contains the instances of on-note *Vorschlag* interpretation.

	Grace 1		Grace 2		Grace 3*	
	# of subjects	mean k and l (S)	# of subjects	mean k and l (S)	# of subjects	mean k and l (S)
k > 0 & l < 0	5	k = .29 l = -.041	7	k = .046 l = -.064	6	k = .037 l = -.038
k = 0 & l < 0	8	k = .001 l = -.052	5	k = .004 l = -.097	4	k = .002 l = -.073
k > 0 & l = 0	2	k = .046 l = .004	1	k = .059 l = -.026	4	k = .071 l = -.007
k > & l > 0	1	k = .278 l = .138	3	k = .313 l = .165		

* S4 is not listed in the list of grace 3. His timing data yielded no significant fits in the analysis of both k and l.

Table 9: Number of subjects performing the accompaniment main note in between the grace and the melody main onset (k > 0 & l < 0), roughly simultaneously with the main note (k = 0 & l < 0), roughly simultaneously with the grace note (k > 0 & l = 0) and before the grace note (k > & l > 0). Mean differences between A' and a' (k) and between A' and a' – c' (l) are reported per subject group.

Further examination showed that only a few subjects consistently fall within one category. Also, no clear differentiation exists between the three grace notes (which is in line with the lack of main effects in the MANOVA). We therefore interpret the results of this analysis as indicating that generally the accompaniment previous IOI is as long or a little shorter than the previous melody IOI. Only in some instances does the accompaniment previous IOI become as short as the melody previous to grace IOI. We do not have an explanation for this exception. When, however, the grace note is performed as an on-note *Vorschlag*, the accompaniment previous IOI is shorter than the melody previous IOI and than the melody previous to grace IOI.

Model

The success of the previous analyses provided the motivation for a model of grace note timing. It can be summarized as follows:

1) The duration of a grace note scales linearly with tempo.
2) The insertion of a grace note only effects the timing of the preceding and following melody notes.
3) The timing of these notes is affected by stealing time from them.
4) The time stolen is a proportion of the grace note duration, irrespective of tempo.

Thus the model consists of two parts, one of which predicting duration the other position. It is given as input a tempo and the timing of two notes performed without a grace note. Its first part predicts the duration of the grace note and the second part determines how it is inserted and how it affects its direct context (see figure 13). The model comprises four

parameters: two for the grace duration and two for the grace position. These parameters depend on the type of grace note and the interpretation in the context of a musical fragment by the performer.

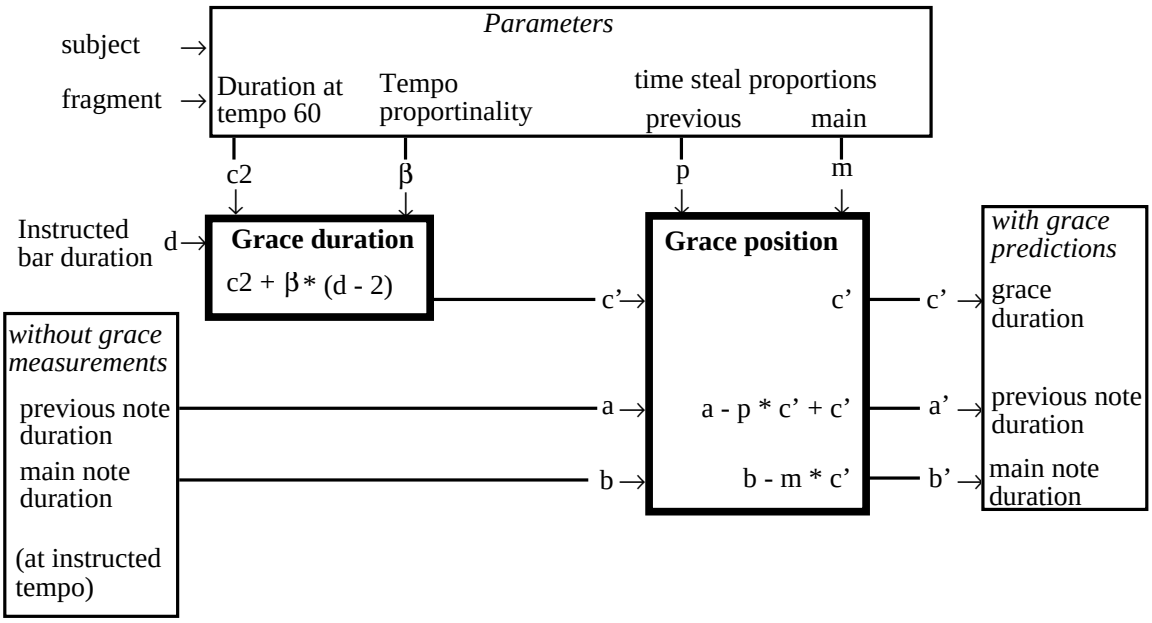


Fig. 13: Overview of input, output and transformations (bold) of the grace note timing model.

The input to the first component of the model consist of the global tempo, we take instructed tempo (t). The parameters are the grace duration at tempo 60 (c_{60}) and the slope of the linear relation between bar duration and grace note duration (β). The output consists of the predicted grace note duration (c'). This duration follows from formula 8, which is derived from formula 4:

$$c' = c_{60} + \beta * \Delta \text{ bar IOI} \qquad \Delta \text{ bar IOI} = 2*60/t - 2 \qquad (8)$$

The input to the second component of the model consists of the grace duration (given by the first component of the model), and the duration of the previous and main note of the performance without the grace note (a and b). The parameters of this component are previous stolen proportion (p) and main stolen proportion (m). The output consists of the predicted duration of the previous and main note of a performance with grace note (a' and b'). These durations follow from the formulas 9 and 10:

$$a' = a - p*c' + c' \quad (9)$$

$$b' = b - m*c' \quad (10)$$

These formulas are derived from formulas 1 and 2.

The parameter values per subject and per fragment that serve as input to the model are the same as in the analyses (see tables 5 and 8 for a summary).

To further validate the model, it was applied to the Beethoven data. Because the subjects were shown to interpret some grace notes differently, we choose to evaluate the model on a per-subject basis, thus parameter values were calculated separately for each performer within each fragment. These values were then used to predict a', b' and c' on ground of a and b of each performance. This will yield the best possible fit between model and data.

Because we aim at accurate absolute predictions of time intervals, reporting correlations between observed and predicted values as error measure is inappropriate. We choose to measure agreement between the predicted a', b', c' and the observed a', b', c' by comparing the variance of the error of the predicted (û) values to the variance of observed values and expressing this as a proportion of the variance observed. The measure is given by formula 11. It was suggested by Erik Maris[6] (personal communication).

$$PRE = (Var\ u - Var\ (u - \hat{u})) / Var\ u \quad (11)$$

The prediction relative error (PRE) approaches 1 when the variance between subjects is much larger than the variance of the observed and predicted difference. PRE becomes 0 or negative when the variance of the difference between observed and predicted is larger than the between subject variance.

All PRE values obtained were high. This good fit concerns the observed and predicted values of the main and previous duration for all tempi (all above 0.97). The fit between observed and predicted values of the grace duration is good as well, though the PRE tends to be a bit lower (though still above 0.7) for the grace duration than for the previous and main duration. This somewhat lower PRE for the grace duration is related to the larger variability of the grace note duration within subjects and its less strict relation with instructed tempo. The average values of PRE for a', b' and c' (averaged over tempi) are given in table 10.

Fragment	a' combined	b' combined	c'
1	.994	.996	.924
2	.987	.989	.847
3	.993	.992	.826

Table 10: Mean PRE of predicted previous IOI (a'), main IOI (b') and grace IOI (c') and observed values of a', b' and c'.

As a comparison of the performance of the model, we calculated the PRE for a' and b' taking a and b as predictors. In other words, we examined the predictive power of a base-line model that expects the duration of the previous and main note to be the same in the with grace note condition as in the without grace note condition. The average values of the PRE are given in table 11. It can be seen that this base-line model predicts the two durations much less well than the above proposed grace note timing model. We may conclude that the grace note timing model predicts the grace duration and the previous and main duration well, since predicted values closely approach the observed values.

Fragment	a' combined	b' combined
1	.067	.079
2	.055	.151
3	.580	.499

Table 11: Mean PRE of the previous IOI of the 'without' condition (a) predicting the previous IOI of the 'with' condition (a') and the main IOI of the 'without' condition (b) predicting the previous IOI of the 'with' condition (b').

Summary and Discussion

The predictions concerning the timing of grace notes were mainly based on grace note category. The type of grace note determined the timing characteristics. The predictions were that, if the grace note was considered an on-note *Vorschlag* (like the *appoggiatura*

proper), all time was stolen from the main note, the accompaniment was performed simultaneous with the ornament, and the duration of the grace note was either a fixed part of the original main note (in case of a long *appoggiatura*) or a smaller fraction of the original main note (in case of a short *appoggiatura*). If, however, the grace note was considered a pre-note *Vorschlag*, all time was stolen from the previous note, the accompaniment was performed simultaneous with the melody main note, and the duration of the grace note was typically short and remained short with decreasing tempo. A third type of grace note interpretation was as an insertion *Vorschlag*: all time was inserted, no time was stolen. This type did not predict a specific position of the accompaniment. The duration of the grace note would be short and remained short with decreasing tempo, since the insertion grace was suggested to act as the insertion of a micropause.

Grace 1 was predicted to be performed as either one of the three grace note types, depending on the taste of the performer. In any case, it would be a short grace note. Grace 2 was predicted to be performed as a long on-note *Vorschlag*. Grace 3 again could be performed as either one of the three case, most probably short, but it might also be performed as a long on-note *Vorschlag*, because of its suspension function.

The results showed significant differences between the three grace notes, but these differences were less categorical than assumed in the predictions. The general trend was to perform all three grace notes as pre-note *Vorschläge*: most or all time was stolen from the previous note, little to no time was stolen from the main note, and the accompaniment note was performed roughly simultaneously with the melody main note.

Grace 2 differed from grace 1 and 3, because on average less time was stolen from the previous note and more time was stolen from the main note. It also differed from the other graces, because two subjects clearly changed their interpretation of the ornaments in fragment 2 with respect to fragments 1 and 3. These two subjects performed the second grace note as a short on-note *Vorschlag*: most time stolen from the main note, no time stolen from the previous note, the accompaniment main note simultaneous to the ornament (even slightly anticipated), and duration less than one third of the main note. There was one subject who consistently interpreted all three grace notes as an on-note *Vorschlag*, stealing all their time from the main note and no time from the previous note, and performing the accompaniment main note simultaneous with the ornament (even slightly anticipated).

Unexpectedly, the ornaments were never performed as insertion *Vorschläge* - with all time inserted. The time inserted was generally small or equal to zero. For fragment 1, the influence of the grace note was slightly unexpected. Grace 1 showed a negative insertion proportion, which was suggested to be related to the faster target bar and post bar in the 'with' condition than the 'without' condition. This faster target bar and post bar might be due to a difference in phrasing between the 'with' and 'without' conditions, which was suggested by some of the pianists. While in 'without' condition the melodic movement of fragment 1 gradually leads towards the high e of the post bar, in the 'with' condition, the movement is towards the grace note and the following main note. If the melodic movement is accompanied by an accelerando, this acceleration occurs earlier in the 'with' condition than in the 'without' condition.

The prediction for the scaling of grace note duration with tempo was that longer grace notes would scale in a relationally invariant manner with context duration similar to the ‘normal’ behavior of structural notes. Short grace notes would however scale less than relationally invariant or would even have invariant duration.

The results on this matter were mixed. In general, no systematic difference in scaling behavior between longer and shorter grace notes was found: the mean length of grace 2 was longer than that of grace 3 and grace1, their average scaling behavior was however always less than relationally invariant. When subject differences were taken into account, we did find that the longest grace notes scaled like ‘normal’ structural notes, while the shorter graces varied less with tempo. Within this group of shorter graces a systematic effect of grace duration was again not present. We found instances in which the duration of relative short grace notes remained invariant with tempo as well as instances that behaved relationally invariant with tempo. Similarly, long grace notes were performed with constant or with (less than) relationally invariant duration.

A grace note timing model was proposed, which states that the grace duration depends linearly on global bar duration, and that the addition of a grace note effects the timing of a musical piece only locally by shortening the note preceding the grace note and following the grace note. The amount of shortening and the slope of the linear relation are parameters, the value of which depends on the performer and the fragment. The performance of the model was tested on the Beethoven data and showed a very high predictive power.

If we were to give treatise-type advice to players based on the model and the practice as we have observed, we first would advice to keep tempo as much as possible (little time

insertion). Secondly, it is an idea to adapt the length of the grace note to the duration of the main note and, thirdly, not to hesitate to perform the grace note in time of the previous note, but also to try out on the beat interpretation. On the beat interpretation needs a longer grace note, which is possible when the main note has sufficient duration. In case of pre-note interpretation, the accompaniment main note should be performed simultaneously with or a little bit ahead of the melody main note. When the grace note is performed on the beat, the accompaniment must not be later than the grace note. It may even anticipate the grace note.

We would also advice to practice in different tempi and to pay attention to the duration of the grace note: slower tempi allow for longer grace notes than faster tempi, but the short character of the grace note should remain, in other words, the duration of the grace note is less flexible than the duration of structural notes.

Conclusions

The model proposed in this paper allows the accurate reproduction of grace note timing given that the timing of surrounding notes is known and the parameter settings can be adjusted manually or be fixed according to a given grace note type. The model allows for an ‘intelligent’ method of inserting grace notes into performances and for an ‘intelligent tempo control’ that would modify grace note timing.

We conclude that we have confirmed the existence of two ornament categories that have distinct timing characteristics: the pre-note *Vorschlag* and the on-note *Vorschlag,* which are known as grace notes or *appoggiatura* performed before or on the beat in performance practice literature. We however also found consistent differences in the

timing of a single ornament category, the pre-note *Vorschlag* as we call it. These differences could partly be related to the musical context in which the grace notes occurred and partly to subject specific interpretation.

We further conclude that the grace notes in this study are timed differently from their structural counterparts. Stolen time seems a consistent aspect of grace notes, as well as less than relationally invariant scaling. It seems therefore no coincidence that the duration of a grace note is not specified in the musical score, while other notes receive a written notation that is related to their idealized proportional duration.

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[1] This Beethoven theme was also used in Desain & Honing (1994) and Windsor et al. (in press).
[2] grace notes 1 and 5 in Windsor (in press)
[3] The average deviation of the pre bar duration from the instructed bar duration is maximally –4.3%, which is the mean deviation for grace 2, instructed bar of 2.67S, which shows the largest discrepancy. Largest individual deviations that occur do not exceed 12%.
[4] The faster tempo of the next note is enlarged, since it concerns the local tempo of a sixteenth note. This means that the absolute difference between with and without does not need to be large to give a considerable difference in local tempo.
[5] The average asynchrony between melody and accompaniment notes is 12ms in the 'without' condition (melody leads).
[6] NICI, University of Nijmegen.