Preparing for memorized cello performance: the role of performance cues

Psychology of Music

Psychology of Music

Society for Education, Music and Psychology Research
1–28
10.1177/0305735608100377
http://pom.sagepub.com

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ABSTRACT An experienced cello soloist recorded her practice as she learned and memorized the Prelude from J.S. Bach's Suite No. 6 for solo cello and gave 10 public performances over a period of more than three years. She described the musical structure, decisions about basic technique (e.g., bowing), interpretation (e.g., dynamics), and five kinds of performance cues she attended to during performance (expressive, interpretive, intonation, and basic technique separately for left and right hand). The 38 hours of practice provide the most comprehensive empirical account to date of preparation of a new piece of music for performance. The cellist repeatedly took the piece apart section-by-section and then re-integrated the sections into practice performances in each of five stages: exploration, smoothing out, listening, reworking and preparation for performance. The location of starts, stops and repetitions identified the changing focus of practice in each stage. The cellist organized her practice around the musical structure, developed interpretation before working on technique and practised memory retrieval at each stage. When she wrote out the score from memory, better recall of expressive and structural performance cues showed that they served as landmarks in a hierarchical memory retrieval organization.

KEYWORDS: *expert memory, music performance, music practice, performance cues, problem solving*

Playing from memory is a central feature of professional competence for concert soloists in the western classical tradition (Chaffin, Logan, & Begosh, 2009). The demands placed on memory are extraordinary and, not surprisingly, memory and attentional lapses are not uncommon. An important part of the artist's preparation of a piece for performance is developing a flexible memory retrieval system that will permit the performance to continue, whatever may go wrong (Chaffin, 2007;

Chaffin, Imreh, & Crawford, 2002; Chaffin & Logan, 2006; Ginsborg, Chaffin & Nicholson, 2006; Hallam, 1995; Lehmann & Ericsson, 1998; Noice, Jeffrey, Noice & Chaffin, 2008). Here, we describe how an experienced cello soloist (the second author) prepared the complex and technically challenging Prelude of J.S. Bach's Suite No. 6 for a series of public performances. We used improved methods to test the conclusions of earlier longitudinal case studies about the application of expert memory theory to musical performance; we extended those conclusions to a stringed instrument; and, for the first time, we followed a piece through repeated public performances.

Expert memory

The feats of expert memorists have been explained in terms of three general principles: meaningful encoding, use of a well-learned retrieval structure and extended retrieval practice (Ericsson & Kintsch, 1995; Lehmann & Gruber, 2006). First, experts' knowledge of their domain of expertise allows them to encode new information in terms of schemas already stored in memory (Brewer, 1987). For a musician, these include familiar patterns such as chords, scales and arpeggios, whose practice forms an important part of training (Halpern & Bower, 1982). Second, expert memorists use a retrieval scheme to organize the cues that provide access to the chunks of information in long-term memory (Ericsson & Oliver, 1989). For a musician, the formal structure of the music provides a ready-made hierarchical retrieval organization (Chaffin & Imreh, 2002; Williamon & Valentine, 2002). Third, prolonged practice decreases retrieval time to the point where an expert can rely on long-term memory to perform tasks for which most people would use their faster, yet smaller capacity, working memory (Ericsson & Kintsch, 1995). For the musician, this involves practising memory retrieval until it is rapid and reliable enough to keep pace with the performance (Chaffin et al., 2002, pp. 216–229). Our study focused on the second and third of these principles.

For musicians, practising memory retrieval involves establishing *performance cues* – those aspects of the piece that the musician is able to deliberately attend to during performance without disrupting the automaticity of highly practised motor sequences (Chaffin et al., 2002). Performance cues are landmarks in the mental map of the piece that a musician monitors during performance to ensure that critical aspects of the performance go as planned, e.g., a fingering that sets the hand up for what follows. They are created by repeatedly attending to a particular feature of the music during practice so it comes to mind automatically during performance, eliciting from memory the thoughts and actions that have been linked with it during practice. Experienced performers strategically place performance cues at key points to provide a safety net in case a performance is disrupted by memory failure or a lapse in attention.

We distinguish four main types of performance cues. *Structural* cues are critical places in the formal structure of the music, such as section boundaries. *Expressive* cues represent the main musical turning points of the piece where the musical feeling changes, e.g., excitement. *Interpretive* cues are places where some aspect of interpretation requires attention, e.g., a change of tempo. *Basic* cues represent

critical details of technique that must be executed as planned for the performance to unfold as intended, e.g., changes in direction of bowing. Basic and interpretive cues include just a few of the myriad decisions made during practice. Most decisions become automatic with practice. Only the few that are singled out for continued attention become performance cues.

Figure 1 summarizes this account, showing a hypothetical retrieval scheme for the *Prelude*, based on previous studies (e.g., Chaffin et al., 2002, p. 200). Expressive performance cues are aligned with beginnings of major sections to provide the top level of a retrieval hierarchy. Subsections and bars provide additional, lower levels in the organization.

We propose that most experienced performers make use of a hierarchical retrieval scheme of this sort because it makes memory *content-addressable* (Chaffin et al., 2009; Rubin, 2006), providing the safety net needed when things go wrong. Normally, memory for a performance is activated by *serial cuing*; auditory and sensori-motor feedback from the current passage elicits the memory of what comes next. When a performance is interrupted, however, the serial chain of cues is broken. In such cases, the musician must be able to generate his/her own cue to restart the performance. For example, by thinking 'G section', the musician could recover by jumping forward to this section, thus avoiding the ignominy of going back to the beginning. A content-addressable retrieval organization like that in Figure 1 makes such a recovery possible.

The first purpose of the present study was to see whether this account of performance memory applies to a stringed instrument and, if so, what kind of performance cues would be used by a string player. The Prelude provided an appropriate comparison with the only other study of a professional soloist learning a substantial piece over many months, Chaffin et al.'s (2002) study of a pianist learning the third

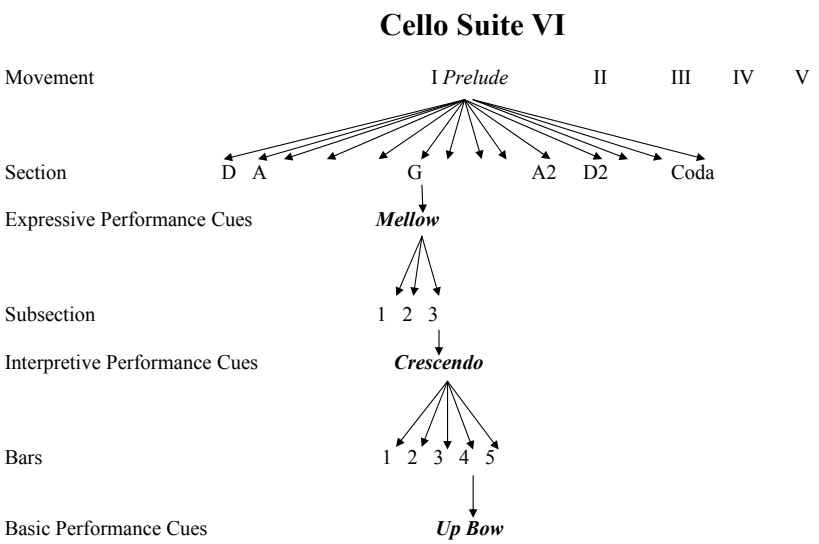

FIGURE 1 *Diagram of the hierarchical organization of Bach's Suite No. 6 for solo cello opened to show performance cues for bar 68 of the Prelude.*

movement (Presto) of J.S. Bach's 'Italian' Concerto. The two pieces are of comparable length, by the same composer, and have a similar stature as important works in their respective repertoires. We expected that, as in the Presto study, the cellist would use the hierarchical organization of the music as a retrieval structure and engage in extended practice of performance cues to bring retrieval up to the speed needed for performance.

Combining first- and third-person perspectives

An unusual feature of our study is that the musician whom we studied is an author of this report. This reflects the central role in our study of the cellist's own understanding of her experience in learning the Prelude. Her first person perspective as the musician informed every decision about the study: which piece to study, which aspects of the music to examine and to how to interpret the data. The first-person perspective of the musician complemented our third-person observations of her practice. On the one hand, experienced musicians can provide detailed and insightful self-reports about their practice and memorization strategies (Hallam, 1995), but the validity of retrospective self-reports is open to question (Ericsson & Simon, 1980). On the other hand, third person observation of practice provides a detailed behavioural record, but is hard to interpret (e.g., Gruson, 1988). When the two perspectives are combined, self-reports help to interpret the behavioural record that, in turn, validates the self-reports. When approached in this way, music practice provides a natural laboratory for studying the development of a complex skill (Chaffin & Imreh, 2001).

To minimize effects of the cellist's expectations about the study on her practice, she initially focused on her role as a performer. She knew only that the study involved detailed examination of practice and would continue through several public performances. Her initial reports of musical structure, 15 months into the study, increased her understanding of the reports that she would be asked to give. She continued, however, to avoid reflection about the learning process or reading the work of the first author until a visit to the USA to perform the Prelude provided the opportunity for extended discussion with the other authors (after session 57, 19 months into the study).

CELLIST'S SELF-REPORTS

The cellist provided two kinds of reports on her subjective experience of learning the Prelude: concurrent and retrospective (Ericsson & Simon, 1980). First, she was asked to talk to the camera from time to time during practice to explain what she was doing. Second, the cellist provided retrospective reports about every aspect of the music that she thought about during practice: technique, interpretation, musical structure and performance cues. Figure 2 shows how she reported bowing decisions (top panel) and basic performance cues for bowing (bottom panel) for bars 65–70 by marking their location in the score with arrows. The example also illustrates how decisions about technique were related to their corresponding performance cues. With practice, the bowing decisions became automatic. The cellist discovered, however, that she was having problems confusing bars 68 and 69 with the very

similar passage in bars 66 and 67. She decided to attend to bowing at the beginnings of bars 68 and 69 to help her distinguish the two passages. In this way, a decision about bowing became a performance cue.

We compared the cellist's retrospective reports with transcriptions of practice and with her recall of the score. Correspondence between the first-person reports and the third-person behavioural measures validated the reports and provided evidence to test our hypotheses about practice and memory. For example, if the cellist started at passages where she reported performance cues for bowing more than at other passages, we inferred both that her report of bowing cues was accurate and that she was practising bowing cues. We also examined the concurrent comments and will report them for the passage shown in Figure 2 to show how they complemented the retrospective reports and practice data (Chaffin & Imreh, 2001).

Practice: We looked at where the cellist started and stopped during practice as indicators of which aspects of the music she was attending to. We expected that she would start, stop and repeat places where she reported performance cues. Starting at a particular place establishes it as a retrieval cue; stopping may also indicate attention, or a problem; repetition increases the speed of retrieval from memory to the point where it can keep pace with the performance (Chaffin & Imreh, 2001).

Recall: Although not a normal practice activity, writing out the score from memory provides a window into the content-addressable retrieval cues that a musician must rely on when things go wrong during performance. The location of retrieval cues can be identified empirically by the presence of serial position effects in free recall. Recall of an ordered series is generally better for the first item in the series and declines with each succeeding item. At each successive link in the chain there is the possibility that retrieval will fail. The probability of recall, therefore, decreases

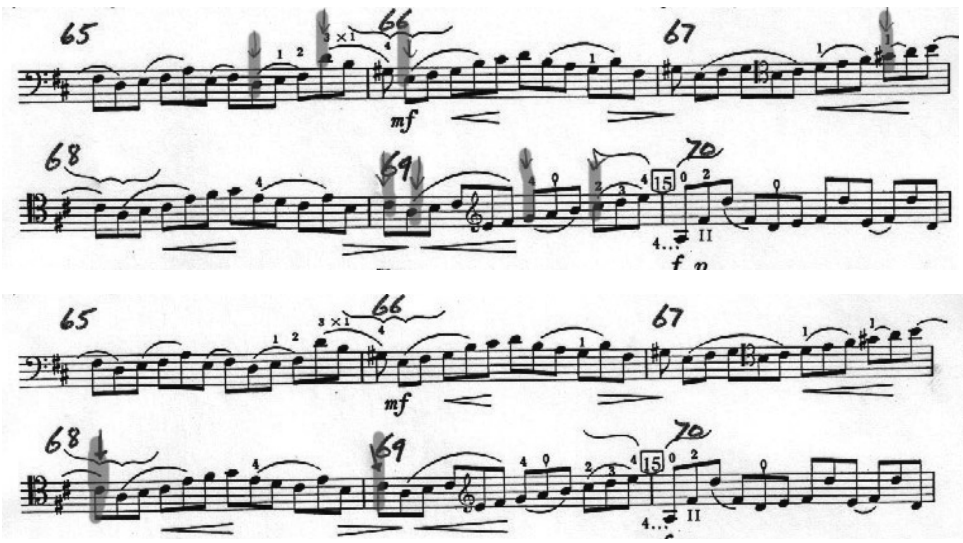

FIGURE 2 *Reports of bowing decisions (top panel) and performance cues (bottom panel) for bars 65–70.*

as distance from the start of the chain increases, producing a *negative* serial position effect (Raaijmakers & Shiffrin, 1981; Roediger & Crowder, 1976).

Two studies of musicians have reported negative serial position effects (Chaffin & Imreh, 2002; Ginsborg & Chaffin, 2007).[1] Recall was better at section boundaries and at expressive performance cues and declined with increasing distance, suggesting that these were the main landmarks in the musicians' mental map of the piece. The same studies also found *positive* serial position effects for basic performance cues. Recall was lower at basic cues and increased with distance from the cue. Basic cues apparently did not provide content-addressable access to memory for the piece. Instead, they were part of the serial chain of associations and needed the sensori-motor context provided by the preceding passage to operate. In writing out the score from memory, this context was not available and basic cues were not operating. As a result, recall was impaired at these points. If the cellist's memory is organized as suggested in Figure 1, we should find negative serial position effects at expressive and structural performance cues and positive serial position effects at basic performance cues.

Stages of practice

The second main goal of this study was to see how practice changed during learning. Wicinski (1950 reported in Miklaszewski, 1989) identified three main stages in learning a new work: preliminary ideas, work on technical problems and trial rehearsals. The pianist in the Presto study identified similar stages (Chaffin et al., 2002). In both studies, the musicians identified the stages from memory, based on general impressions. In the present study, the cellist identified stages after examining the empirical record of her practice and noting the presence of alternating episodes of *section-by-section* practice, in which short sections are repeated, and *integrative* practice, in which the shorter sections are put together (Chaffin et al., 2002, pp. 116–119; Miklaszewski 1989, 1995; Williamon & Valentine, 2000, 2002; Williamon, Valentine, & Valentine, 2002).

We also wanted to see whether the cellist would attend to different aspects of the music as learning progressed. Would she begin with a 'musical image' of the piece (Neuhaus, 1973), knowing how she wanted the piece to sound before she had solved its technical problems (Chaffin, Imreh, Lemieux, & Chen, 2003)? Would she focus on technique before interpretation (Chaffin et al., 2002, pp. 179–187)? When would the different kinds of performance cue develop? In the Presto study, the pianist focused initially on all four types of performance cue during early practice sessions. Then, when she deliberately memorized the piece, she narrowed her attention to structural cues. Later, practice of the other kinds of performance cues reappeared in succession (Chaffin, Lemieux, & Chen, 2006). We wanted to see whether a similar progression would occur with another musician, piece, and instrument and how practice would change as the piece was re-learned for repeated public performance.

In summary, we looked for changes in practice as learning and memorization progressed. On the basis of previous research, we expected that practice strategies would be reflected in where the cellist started and stopped, that practice and recall

would be organized around expressive and structural performance cues, and that performance cues would receive extended practice.

Method

THE CELLIST

Tânia Lisboa was trained as a concert pianist and cellist in her native Brazil before continuing her study of the cello in England, with Richard Markson and Raphael Wallfisch, and France, with Maud Martin Tortelier. She performs regularly as a soloist, worldwide, and normally plays from memory. Throughout the study, she maintained her normal schedule of recital and concert engagements. Prior to this study, she had performed Bach's Suites Nos 1–5 for solo cello and saw the study as an opportunity to add Suite No. 6 to her repertoire.

THE MUSIC

The Prelude from Bach's Suite No. 6 for solo cello explores both the mellow quality and virtuoso aspects of the instrument. The Prelude is musically comparable to the other five Bach cello suites, but presents greater technical challenges because it was written for an instrument with five strings rather than the four strings of the contemporary cello. Notated in 104 bars in 12/8 time, the piece takes about five minutes to perform. The score is shown in Appendix 1.

PROCEDURE

Practice sessions

The cellist video-recorded her practice and public performances from the first time she sat down with the Prelude until the tenth public performance, 75 sessions and three years, five months later. She maintained a log in which she recorded the date, time and main goal of each session. She avoided engaging in mental practice and so our data cover the entire 38 hours 12 minutes of preparing the piece except for 16 sessions in which the cellist worked without the camera to avoid distraction. The total practice time video-recorded was 32 hours 54 minutes. During practice the cellist talked to the camera periodically about what she was doing.

We transcribed practice for each session by recording the half bar where playing started and stopped, and then summarized each session in a practice graph (see Figures 3 and 4). Sessions were grouped together into sets based on inspection of the practice graphs and the location of long breaks during which the piece was not played. Practice was compiled for analysis by counting the frequency of starts, stops and repetitions for each half bar in each session set. The cellist identified stages in her learning following session 67 after reviewing her logbook, the practice graphs, and the grouping of sessions into sets.

Recall

Ten months after the eighth public performance, the cellist was asked to write out the score from memory. She had not looked at the score or played the piece in the intervening months. Probability of correct recall was measured for each half bar by dividing the number of notes correctly recalled by the number of notes in the score.

Bars not attempted were given a score of zero. Notes were scored based upon their position within each half bar; thus omissions negatively affected the score on the rest of the half bar, but not beyond.

Cellist's reports

The cellist reported decisions she made about the piece during practice by marking them on copies of the score (see Figure 2). She provided reports for 19 different dimensions representing all those aspects of the music she considered important (see Table 1). Reports of musical structure and basic dimensions were completed during a three-month break following session 32, 15 months into the study. Reports of interpretive dimensions were done following session 57, 19 months into the study, while traveling to the USA to perform the Prelude. Performance cues were reported two weeks later, at the end of the same trip, following session 67. Most expressive cues coincided with major section boundaries, and so only the former were used for analysis. The cellist saw the piece as organized into 10 expressive/harmonic main sections subdivided into 43 thematic subsections (shown in Appendix 1).

TABLE 1 *Dimensions used by the cellist to report aspects of the music that she thought about and/or practiced*

Basic technique: Decisions needed just to play the notes
Right hand
- Bowing – changes in the direction of the bow on the string (e.g., up or down bows)
- Changing string – moves from one string to another involving string crossing

Left hand
- Fingering – decisions about which particular finger to use for each note
- Hand position – shape and location of hand positions on the fingerboard
- Shifting – moving the left hand to change register

Technical difficulty – unusually difficult movements, e.g., awkward left hand positions
Familiar patterns of notes – e.g., scales, chords, arpeggios

Interpretation: Decisions affecting the musical shaping of the piece
Dynamics – changes of loudness
Sound quality – differences in timbre, 'colours' and types of sound
Intonation – tuning, adjusting pitch
Phrasing – grouping of notes to form musical units

Performance cues: Features attended to during performance
Expressive – feelings to be conveyed to the audience, e.g., tension, peacefulness
Interpretive – sound quality, dynamic, phrasing, and tempo changes
Intonation – nuances of pitch that affect the musical flow
Basic – features of basic technique requiring attention during performance
- Right hand – bowing and changes of string
- Left hand – fingering and hand position

Musical structure:
Section and subsection boundaries – beginnings and ends of harmonic and melodic passages
Switches – places where two repetitions of the same theme begin to diverge

Analysis

Regression analyses compared the cellist's reports with her practice and written recall of the score. The analyses provided a concise description of the most important influences on starts, stops and repetitions. Significant effects indicated regularities that were robust and consistent enough across sessions to show up against the background of all the other influences on practice. The predictor variables represented the features and cues that the cellist reported. The dependent variables were the frequency of starts, stops, and repetitions for practice and probability correct for recall (see Chaffin & Imreh, 2001 for details). The unit of analysis was the half-bar ($N = 208$). Predictor variables were entered simultaneously.

For the analysis of practice, 13 predictors were selected on the basis of exploratory analyses (see Table 3).[2] Reports of musical structure were coded by a dummy variable identifying the first half bar in each subsection, the remaining dimensions by the number of cues or features reported in each half bar. For the analysis of recall, four predictors were used. Serial order from the beginnings of subsections, and from expressive, interpretive and basic cues was coded by numbering half bars successively until the next cue of the same type.[3] Basic cues for left and right hands and for intonation were combined to create the predictor for basic performance cues.

Results and discussion

We observed the development of the Prelude over a period of almost 3.5 years (see Table 2). Practice occurred in three main learning periods separated by two long breaks of eight and 18 months respectively: (1) initial learning, consisting of 26 sessions, totaling 8.5 hours, over three months, (2) first re-learning consisting of 41 sessions, totaling 25.5 hours, over four months, and (3) second re-learning consisting of eight sessions, totaling 4.5 hours, over one month. There were additional shorter breaks of one to four months within learning periods 1 and 2 (Table 2, column 7). Eight public performances took place towards the end of learning period 2, two more at the end of learning period 3 (Table 2, column 8).

Practice alternated between s*ection-by-section* practice in which the cellist worked on the piece in sections and *integrative* practice in which she put the shorter sections together. For example, Figure 3 shows the 33 minutes of practice in session 7. The Figure reads from bottom to top, with each line representing the uninterrupted playing of the bars shown on the horizontal axis. Practice was organized by sections and restricted to the first half of the piece. This was typical of practice in sessions 1–14; the cellist worked systematically from the beginning of the piece to the end, covering a few sections in each session.

Figure 4 shows the first session devoted to integrative practice, session 15, which lasted 52 minutes. Practice was still organized by sections, but extended over the entire piece. The goal of integrating individual sections into a unified performance was evident at the end of the session when the cellist played through the piece for the first time from memory, without interruption. Four more cycles of alternating section-by-section and integrative practice followed (Table 2, column 3).

TABLE 2 *Distribution of practice sessions across 92 weeks showing the duration of learning periods, stages and cycles, and their relation to the public performances*

Learning period	Stage (main goal)	Cycle	Session	Duration (hr/min)	Weeks	Breaks	Public performance
1. Initial learning	1. Explore	Putting-together	1	0:20			
		Section-by-section	1–10	5:38	3		
					6	Break 1	
		Section-by-section	11–14	2.03	2		
	2. Smooth out	Putting-together	15–16	0:48	1		
		Section-by-section	17–20	4:19	3		
	3. Listen	Putting-together	21–26	1:51	3		
					34	Break 2	
2. First re-learning		Putting-together	27	0:10			
		Section-by-section	28–30	1:50	1		
		Putting-together	31–32	0:43	1		
					16	Break 3	
	4. Rework technique	Section-by-section	33–35	2:24	1		
	5. Prepare performance	Putting-together	36–37	0:41	1		
		Section-by-section	38–44	1:38	3		
		Putting-together	45–47	0:29	1		1–2
					5	Break 4	
		Not recorded	48–53	3:02			
		Putting-together	54–67	8:04	1		3–8
					82	Break 5	
3. Second re-learning		Putting-together	68–69	0:49	2		
		Putting-together	70–72	2:12	1		
		Putting-together	73–75	1:16	1		9–10

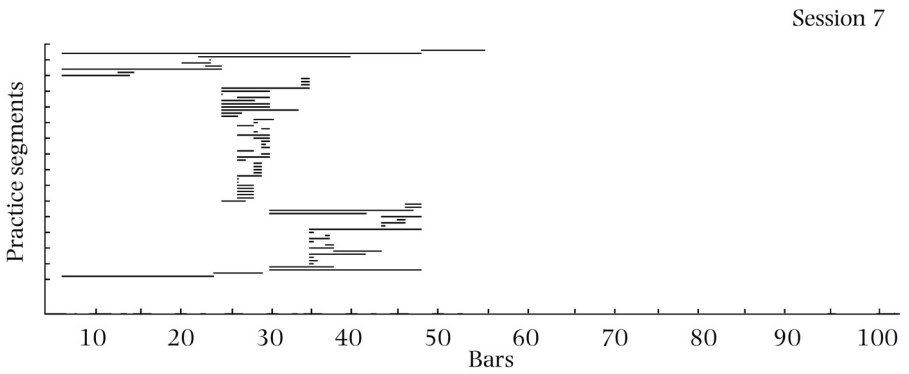

FIGURE 3 *The practice record for session 7 provides an example of section-by-section practice.*

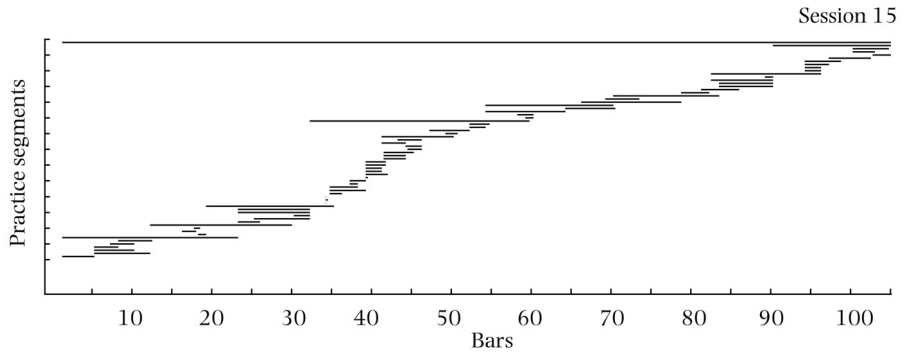

FIGURE 4 *The practice record for session 15 shows the first session devoted to putting-together practice. The cellist worked through the entire piece in sections and then put everything together to play from beginning to end for the first time without interruption and from memory.*

STAGES OF LEARNING

The cellist identified five stages in her learning (Table 2, column 1): Explore, smooth out, listen, rework technique and prepare performance. These stages correspond well with those identified by Wicinski (1950, reported in Miklaszewski, 1989) except that Wicinski's last two stages were repeated. The correspondence is as follows (with Wicinski's stages in italics): explore (*initial ideas*), smooth out (*work on technical difficulties*), listen (*trial rehearsals*), rework technique (*work on technical difficulties*), prepare performance (*trial rehearsals*). We will first describe each stage based on the practice graphs, logbook, and spontaneous comments during practice.

Exploration (sessions 1–14)

The cellist began her exploration of the expressive and technical possibilities of the piece by sight-reading through it, putting the piece together for the first time. She then focused on successive sections in each session until she reached the end of the piece in session 10 (e.g., Figure 3). At this point she was obliged to interrupt her practice while the camera was repaired. When she returned to the piece after a six-week break, she worked through it again, section-by-section, in sessions 11–14.

Smoothing out (sessions 15–20)
Sessions 15 and 16 were devoted to integrative practice as the cellist learned to play through the entire piece from memory. Figure 4 shows that session 15 ended with an uninterrupted performance of the entire piece. This was the first performance from memory. The cellist said before she started playing, 'I'm going to keep the music here, but see if I can remember most of it. If I can't, I'll just look', and as she finished: 'Ok, I just about know it. I think it's memorized.' This was typical. The cellist practiced with the score open, but played from memory as much as possible.

Smoothing out continued with section-by-section work on technique in sessions 17–20. Decisions about fingering and bowing were re-evaluated; intonation and speed of vibrato were adjusted; and jerky left-hand movements during string changes were smoothed to eliminate unwanted accents. At the end of session 19 the cellist announced: 'I feel I am ready to move on ... I know the notes, bowing and fingering ... I need to think about phrasing [and] harmonies [to] bring them out.'

Listening to the music (sessions 21–32)
After two hours of work on phrasing and harmonies in sessions 21–26, the cellist put the piece aside for eight months, bringing to an end the first learning period. Work resumed when she took the opportunity offered by a rehearsal of other repertoire in London's Wigmore Hall to see how the Prelude sounded in a 'proper' hall. She was pleased to find that it was: '[a] wonderful feeling! It is starting to feel ... [like] a real performance.' Section-by-section practice in sessions 27–30 was followed by putting the piece together again in sessions 31 and 32.

Re-working technique (sessions 33–35)
The cellist then took a four-month break, during which time she listened to another musician's performance of the piece. She returned to the Prelude with new ideas for fingering and bowing that were implemented in three long sessions of section-by-section practice.

Preparing for performance (sessions 36–75)
From this point, most sessions involved putting-together practice as the cellist prepared for the first public performance, less than a month away. The first two performances, in Brazil, were followed two months later by two in the UK. Three weeks later another four performances in the USA brought the second learning period to an end. After an 18-month break, the cellist learned the piece again for another public performance given in connection with a report on the research at a psychology conference (Lisboa, 2006).

EFFECTS OF MUSICAL STRUCTURE AND PERFORMANCE CUES ON PRACTICE

The practice graphs in Figures 3 and 4 show that the cellist started and stopped in some places more than others. What was special about these places? Her reports provided the answer. She started and stopped mainly at expressive cues and at subsection boundaries. This conclusion is based on much more than the small samples of practice shown in Figures 3 and 4. The regression analyses examined every practice session and 13 different aspects of the music. The significant effects ($p < .01$)

summarized in Table 3 confirm our description of Figures 3 and 4. The cellist started at expressive cues in sessions 1–10 and started and stopped at beginnings of subsections in sessions 15–16 more frequently than at other locations. The more complete report of the analyses in Appendix 2 shows that the cellist's reports, represented by the predictors, were reliably related to practice, accounting for between 12% and 47% of the variance (mean $R^2 = .30$).[4]

Most of the effects in Table 3 are positive, indicating that the cellist started, stopped and repeated the features and cues in question *more* than other places, i.e., she practised them. Negative effects indicate *fewer* starts, stops or repetitions, suggesting that the cellist was either postponing work on them until later or practising in context, playing through features or cues without stopping (Chaffin et al., 2002, pp. 183–185).[5]

We will examine how practice changed across sessions, focusing first on two types of effect that are especially informative. Starts (highlighted in Table 3) are often the result of a deliberate choice, while starts, stops and repetitions at the same place (bold face italics in Table 3) indicate intense practice of short segments. Both starts and intense practice show that, despite the technical difficulty of the piece, the cellist was more concerned with interpretation than technique. Both show that she used expressive and structural cues as starting places from the outset and did not focus on technical difficulties until the end. Given the unusual technical difficulties of the Prelude, it is striking that they were not practised intensively until sessions 58–67 and that intensive practice of performance cues for left hand (the locus of most of the difficulties) did not occur until sessions 70–72.

The cellist used expressive performance cues as starting places at the beginning of all three learning periods, indicating that she started work each time with the musical 'big picture' in mind (Chaffin et al., 2003; Neuhaus, 1973). In each learning period, these effects were also accompanied or followed by starts at lower levels of musical structure, suggesting that she was thinking of the music in terms of its hierarchical organization. Starting at expressive and structural cues early on in practice would have established the hierarchical structure of the piece as a retrieval organization (Chaffin & Imreh, 2002; see also Miklaszewski, 1989; Williamon & Valentine, 2002).

Within the framework provided by expressive cues and subsections, the cellist focused on other aspects of the music. Her starting points were initially places where she made decisions about dynamics (sessions 1–10), then phrasing (sessions 11–14). As she started playing from memory, she established basic performance cues for the right hand (bowing) to help her remember (sessions 21–30). Intensive practice of interpretive performance cues came next (sessions 33–35), followed by attention to sound quality (sessions 36–57) and intonation (sessions (54–57). The first re-learning period ended with renewed attention to phrasing and intensive practice of technical difficulties (sessions 58–67). The latter continued in the second re-learning period (sessions 68–75) when it was combined with the first intensive practice of performance cues for left hand (sessions 70–72).

The remaining effects (i.e., those not highlighted or bold italic in Table 3) fill in details of this account. We will focus on the effects of performance cues. Practice of basic performance cues began during the smoothing-out stage, as the cellist learned

TABLE 3 *Summary of significant effects ($p < .01$*) of performance cues, interpretation and basic technique on the frequency of Starts (B), Stops (E) and Repetitions (R) as a function of learning phase, stage and session set, with effects on starts highlighted and effects on all three measures at the same time in bold italics*

Learning phase	1. Initial Learning					2. First re-learning						3. Second re-learning		
Stage	1. Explore		2. Smooth out		3. Listen	4. Re-work				5. Prepare performance				
Type of practice	section	section	integrate	section	integrate	section	integrate	section	integrate	integrate	integrate	integrate	integrate	integrate
Session set	1–10	11–14	15–16	17–20	21–26	27–30	31–32	33–35	36–47	54–57	58–67	68–69	70–72	73–75
Structural cues														
Expressive/sections	B	B E		E		E	B	B	B	b		B		
Subsections	B E	B	B E	B E	B	b							b	BE
Switches	E					E								
Performance cues														
Interpretive								***B E R***		B	E R			
Intonation								E R			E R			R
Basic: left hand				E R		E R		E					***B E R***	
Basic: right hand					B E	B R				-E				
Interpretation														
Dynamics	***B E R***										-R			
Sound quality	R			R				R	***B E R***	***B E R***				E R
Intonation	R			-E	E R	-E			R	***B E R***				
Phrasing		B R									B			
Basic technique														
Hand position	R	R	R		-R	R			R					
Fingering														
Bowing/change string		E					E R		E					
Technical difficulties					E R					E	***B E R***	***b E R***	***b E R***	***B E R***

* Effects on starts that were significant at the $p < .05$ level and were adjacent to cells in which the same effect was significant at the $p < .01$ level are included and are represented by a lower case 'b'.

to play fluently from memory. Cues for the left hand (fingering and hand position) came first (sessions 17–20) because they ensured that the notes were accurate. Cues for the right hand (bowing and change of string) came next (sessions 21–26) because they determined how the notes sounded. After practising cues for left- and right-hand cues separately (in sessions 17–20 and 21–26), the cellist was able to practice them together in sessions 27–30, as she relearned the piece after the nine-month break. Practice of basic performance cues continued in sessions 33–35, when stops at left-hand cues indicated that they were not operating up to speed. In sessions 54–57, the negative effect of right-hand cues indicated that the cellist was practising them in context by *not* stopping.

As she began to prepare for the first public performance, in sessions 33–35, the cellist's attention turned to performance cues for interpretation and intonation. It is interesting to note that this analysis of what the cellist actually did in these sessions (Table 3), contradicts her description of sessions 33–35 as 'reworking technique' (Table 2). In this case, first- and third-person perspectives provided substantially different views of the cellist's goals (Chaffin & Imreh, 2001).

COMMENTS ABOUT PERFORMANCE CUES

In other cases, first- and third-person perspectives were more complementary. As an example, we will describe the comments about bars 66–69, the passage used earlier to illustrate the reports of performance cues (see Figure 2). The cellist first noted the potential for confusing bars 66–67 with bars 68–69 in session 8: 'It's exactly the same pattern but ... a [4th] higher.' She commented on it again in session 13: 'Next two bars the same again.' In session 30, another comment suggests that she was confusing the two passages when she played from memory and used the bowing to keep them straight. 'Okay, I forgot completely ... Well, I remembered more than I could remember [last time], and the clues [cues] that I reported to the camera last session actually helped [me] very much to remember where the up-bows are ...' Figure 2 shows the up-bows reported as performance cues in bars 68 and 69. The comment explains why they were needed and suggests that practice of performance cues for right hand in sessions 21–30 (see Table 3) was responsible for the improved memory reported in session 30.

In session 33, the cellist was still having memory problems and suggested: 'Maybe the dynamics would help because I've got a crescendo on the up-bow.' The crescendo is circled in her report of interpretive performance cues for bar 68 and annotated '(visual memory) – bowing' (see Figure 5). The comment, made more than two years earlier, explains what this means: Thinking about the crescendo on the up-bow helped the cellist to keep the two passages straight as she played from memory. The comment supports our claim that performance cues aid in memory retrieval. Together with the intensive practice of interpretive cues in sessions 33–35 (see Table 3), the comment supports the idea that extended practice of performance cues is needed to ensure their smooth operation.

RECALL

Not surprisingly, the cellist's recall showed substantial forgetting after almost 12 months away from the piece; accuracy was 52 percent. As expected, there were

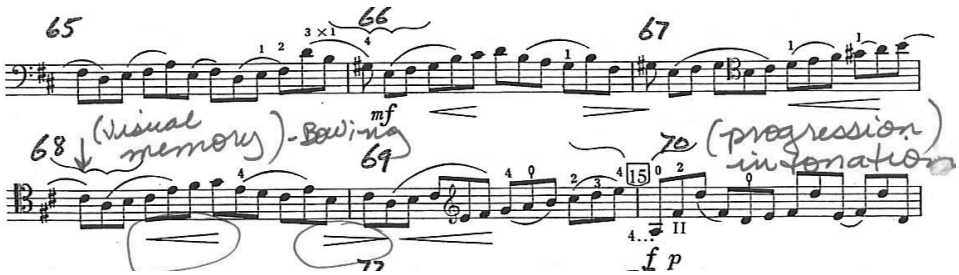

FIGURE 5 *The cellist's report of interpretive performance cues for bars 68–69.*

serial position effects. Figure 6 shows mean recall probability as a function of serial position; Table 4 summarizes the regression analysis that tested the reliability of the effects.[6] Probability of recall was highest at expressive cues and beginnings of subsections and declined as distance increased – negative serial position effects. For basic performance cues the serial position effect was positive – probability of recall was lowest at basic cues and increased with distance.

The effects for expressive cues and subsections suggest that these were the main landmarks of the cellist's memory. Once the beginning of each passage was retrieved, it cued recall of what followed until, at some point, a link failed and the chain was broken, resulting in a poorer recall as distance from the landmark increased (Roediger & Crowder, 1976). Expressive cues were more effective retrieval cues than beginnings of subsections. Recall was nearly perfect at expressive cues and lower at subsection boundaries (M = 0.93 and 0.65 respectively, $t(32) = 2.72$, p = .01). The difference supports the idea that expressive cues marked the highest level in a hierarchical organization and subsections a second level (see Figure 1).

The effect of basic performance cues on recall was in the opposite direction. Recall was lower at basic cues and increased as distance from the cue increased. The effect suggests that basic cues did not provide direct, content-addressable memory access, but operated instead as part of a serial chain of associations, reminding the musician about important details of technique (Chaffin et al., 2009; Rubin, 2006). In writing out the score from memory she was not performing the relevant actions, and so the memories associated with them were less available.

TABLE 4 *Regression coefficients (unadjusted) for the effects of serial position of half-bars from performance cues and beginnings of subsections of the musical structure on probability of correct recall, with R^2 and first-order autocorrelations (negative coefficients represent traditional serial position effects with recall decreasing as distance from the cue increased)*

Effect of serial position from	Regression coefficient
Expressive performance cues	–0.089*
Starts of subsections	–0.072*
Interpretive performance cues	0.005
Basic performance cues	0.066*
R^2	**0.29***
First-order autocorrelation	**0.72***

* $p < .001$

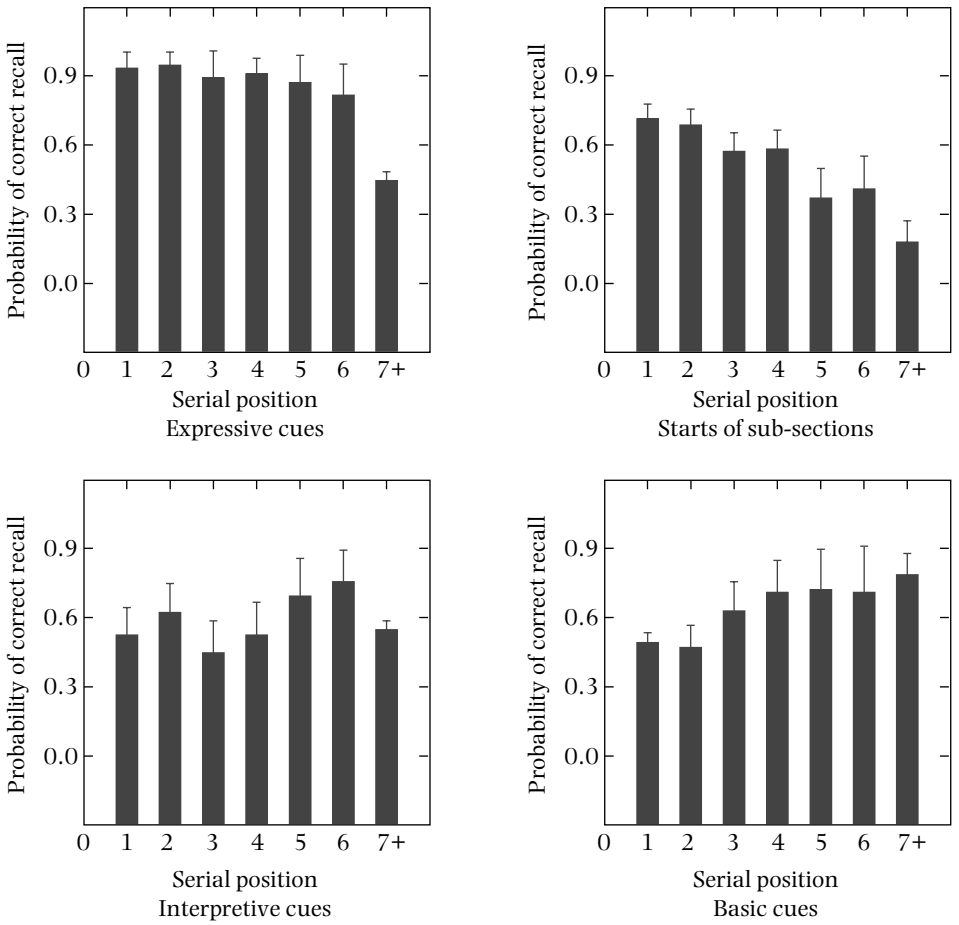

FIGURE 6 *Mean probability of free recall (with standard error bars) for serial position of half bars numbered sequentially starting at expressive performance cues, starts of subsections, interpretive performance cues, and basic performance cues.*

The results are remarkably similar to other studies that have looked at serial position effects for performance cues in written recall (Chaffin et al., 2002, pp. 212–216; Ginsborg & Chaffin, 2007). In each case, there were the same negative serial position effects for expressive and structural cues and positive serial position effects for basic cues.[7]

Conclusion

Our study extends the principles of expert musical memory to a new soloist and, for the first time, to a stringed instrument. Like other experienced soloists who have been studied, the cellist engaged in extended practice of performance cues embedded in a hierarchically organized memory retrieval organization (Chaffin & Logan, 2006). By using a retrieval scheme, musicians can direct attention to different passages in the music at will (Williamon et al., 2002) and recover from mistakes.

Performance cues tell a musician what to do as the performance unfolds, reminding him/her of the actions, musical gestures, and expressive goals chosen during practice, and helping him/her to shape a performance that meets her aesthetic goals (Chaffin, Lemieux & Chen, 2007).

The most direct evidence for the second principle of expert memory, the use of a hierarchical retrieval organization (Ericsson & Kintsch, 1995), came from written recall of the score. Negative serial position effects for expressive cues and subsection boundaries suggested that they provided the main landmarks in the cellist's memory. Expressive cues were recalled better than beginnings of subsections, suggesting that the music was hierarchically organized in the cellist's memory, with subsections nested below expressive cues, as shown in Figure 1. The practice data showed that this memory organization was established at the outset by starting at expressive cues and beginnings of subsections.

Support for the third principle of expert memory, extended retrieval practice, came from the practice data and comments (Ericsson & Kintsch, 1995). The cellist singled out musical structure and performance cues for attention throughout most of the 38 hours of practice. Thinking about a particular feature of the music during practice linked thought to action. Extended practice of the link developed the speed and reliability needed for performance (Chaffin & Imreh, 2002). The comments about bars 66–69 show how the cellist strategically added performance cues to overcome specific memory problems.

The cellist attended to different aspects of the music at different points in the learning process. In her initial exploration of the piece, she attended to expressive cues and musical structure. Like other experts, she began with the 'big picture' (Chaffin et al., 2003; Ginsborg et al., 2006; Lehmann & Gruber, 2006; Neuhaus, 1973). Then, like the pianist in the Presto study, she focused on the formal structure as she memorized the piece (in sessions 15–16), and then focused on basic before interpretive cues (Chaffin et al., 2006). She set up basic cues for left hand (sessions 17–35), and right hand (sessions 21–57) before turning again to expressive cues and setting up cues for interpretation and intonation (sessions 33–67). In re-learning the piece for the last two performances, her attention was on expressive and structural cues along with technical difficulties and their associated performance cues for left hand.

There were similarities and differences with the Presto study (Chaffin et al., 2002, pp. 190–194; 2006, pp. 208–211). Both musicians worked in bursts separated by long breaks. Both worked in cycles of section-by-section and putting-together practice (called 'work' and 'runs' by Chaffin et al., 2002). Both practised performance cues extensively and focused on different aspects of the music as learning progressed. As described in the previous paragraph, both started their practice with a 'musical image' of the piece already in mind, narrowed their attention to focus just on musical structure during initial memorization and worked on basic before interpretive performance cues. Both reworked specific details of technique and interpretation in preparing for performance.

The most striking difference was that the cellist left intensive work on technical difficulties until the end, whereas the pianist did the same work at the outset. The difference was probably due to a combination of individual learning styles and scheduling constraints. The cellist initially delayed work on technical difficulties

until she was sure of her interpretation (sessions 21–26). She then gave priority to interpretation to ensure that her playing was musically developed by the time of the first public performances even though this meant that they were not as good technically as she would have liked.

We believe that most experienced performers memorize in much the same way, with only superficial differences as a result of music, instrument, and learning style. This generalization is based on the consistency of the present findings with previous case studies (Chaffin, 2007; Chaffin et al., 2002; Ginsborg et al., 2006; Noice et al., 2008) and with general principles of memory. Musicians' use of musical structure and performance cues is consistent with principles of expert memory developed from the study of experts in other fields, and with principles of memory derived from the study of the general population (Ericsson & Oliver, 1989). There is good reason to expect, therefore, that the same principles generalize to other experienced performers.

The stages and cycles of practice that we identified may also be characteristic of experienced musicians in general. The stages identified by the cellist are similar to those identified in other studies (Chaffin et al., 2002; Hallam 1995; Wicinski, 1950, reported in Miklaszewski, 1989) and are based more directly on empirical records of practice. Alternating cycles of section-by-section and integrative practice were also noted in earlier studies (Chaffin et al., 2002, pp. 116–119), although our identification of this pattern across sessions is new.

Did the cellist's expectations about the study shape our findings? The need to record herself undoubtedly affected some aspects of the cellist's practice. For example, she refrained from mental practice and sometimes found talking to the camera a distraction. We think it unlikely, however, that the practice strategies we were interested in were much affected by the presence of the camera or the anticipation of reporting decisions. First, the cellist did not know she would be asked to write out detailed reports until late in the study, long after their effects on practice first appeared. Second, preparation for public performance was always her overriding concern and for this she needed to rely on well-established practice strategies.

Solo recitals in the western classical music tradition place extraordinary demands on performers. A performance must be practised to the point that it can be delivered automatically and reliably under pressure. At the same time, it must remain flexible enough to permit recovery from mistakes, which can occur, no matter how thoroughly the musician prepares. The skilled performer achieves flexibility by integrating automatic motor sequences with cognitive control through extended practice of performance cues. Our description of the preparation of the Prelude in 38 hours of practice over a period of nearly 3.5 years provides the most complete description to date of how this is done.

ACKNOWLEDGEMENTS

We thank Mary Crawford for helpful suggestions on an earlier version of the paper, Len Katz for statistical advice, Adrienne Schiaroli, Abby Barrera, Kasia Olechowska and Mark Brundage for transcribing practice and the Werner Icking Music Archive (http://icking-music-archive.org) for providing a copy of the score for publication.

NOTES

1. For the Presto, the pianist wrote out only the first page of the piece, approximately 15 percent of the whole (Chaffin et al., 2002, Ch. 9).
2. Correlations between predictors were mostly non-significant ($r < .24$). There were small to moderate correlations of subsection beginnings with expressive cues, interpretive cues, and beginnings of phrases ($r < .39$) and of performance cues for left hand and for intonation with ratings of technical difficulty and reports of specific decisions about hand position and intonation ($r < .47$). The number of half bars containing the different kinds of cues and features used as predictors varied: beginnings of subsections (43), switches (5), expressive cues (10), interpretive cues (17), basic cues for left hand (93), right hand (56), and intonation (44), technical difficulties (34), sound quality (18), dynamics (109) and phrasing (116).
3. A maximum value of 7 was used, with serial positions of 7 and greater receiving the same value, in order to ensure a minimum of eight observations for each serial position.
4. The R^2 values were substantially higher than those obtained in the study of the Presto (Chaffin et al., 2002). One possible explanation is that our grouping of sessions into sets more accurately reflected the stages of learning.
5. The autocorrelations indicated that the data points were independent for starts and stops (mean = .10 and .13 respectively) but positively correlated for repeats (mean = .64). To test whether the lack of independence for repeats affected the analyses, regression analyses were performed using every third data point. The mean autocorrelations for repeats dropped (mean = .29) while the effects remained largely unchanged (mean R^2 = .41). The analyses of repeats were not, therefore, compromised by lack of independence.
6. An additional mixed hierarchical regression analysis yielded the same results, indicating that the analysis was not compromised by the lack of independence between data points indicated by the substantial autocorrelation.
7. In the Presto study (Chaffin et al., 2002, pp. 214–215), recall was higher at structural than at expressive cues, in contrast to the present finding of higher recall at expressive cues. The difference can be attributed to the fact that the cellist's expressive performance cues represented the highest level in her hierarchical organization of the piece, whereas in the pianist's organization the highest level was represented by structural cues.

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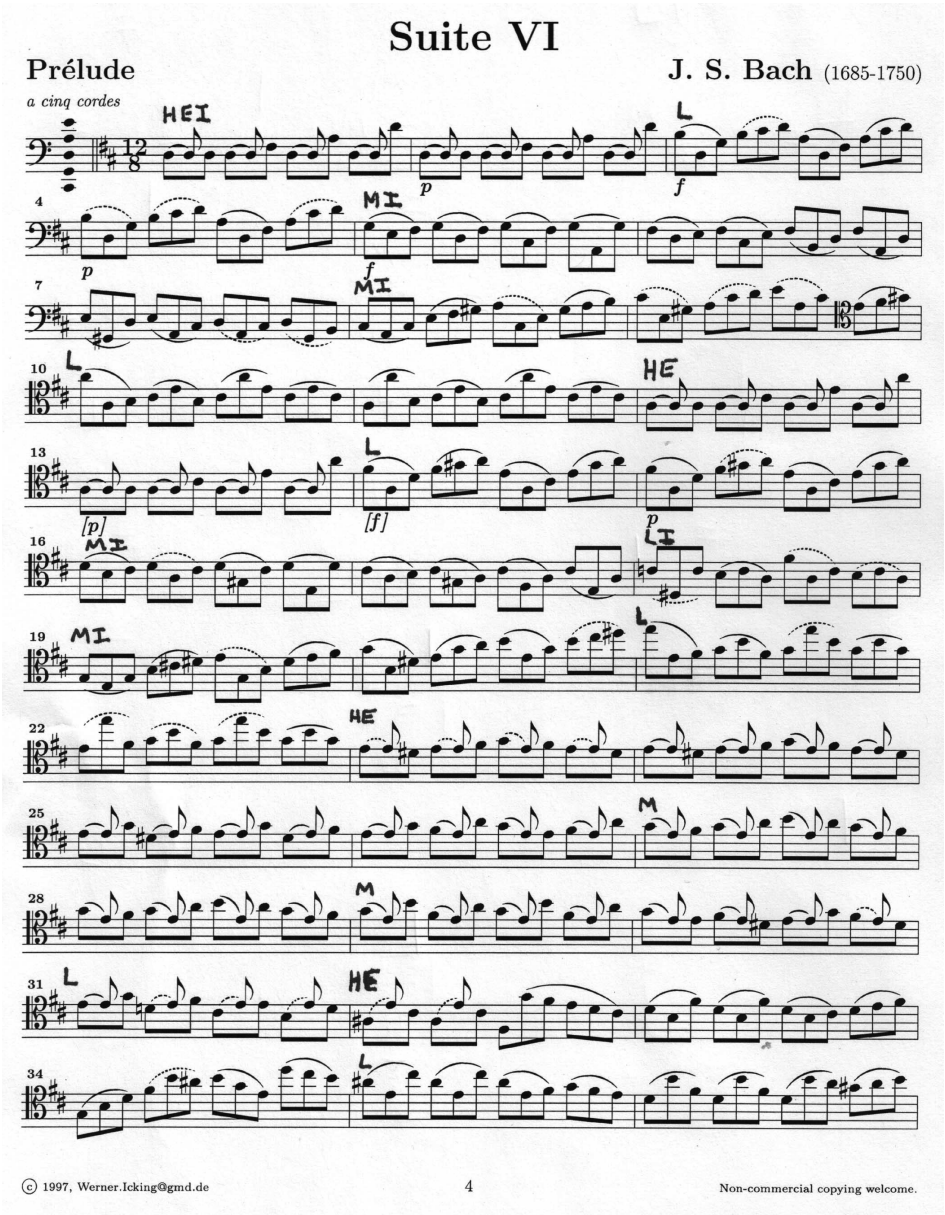
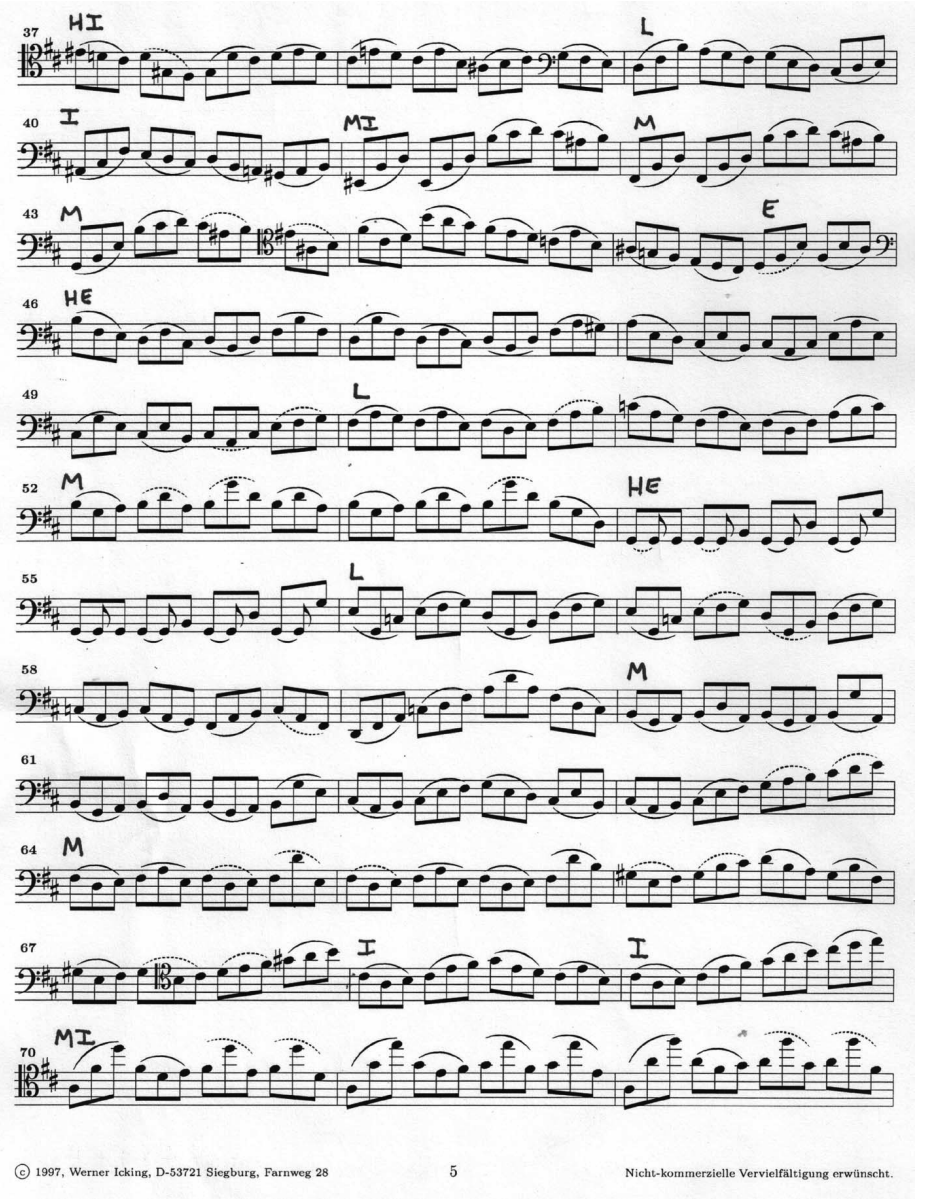
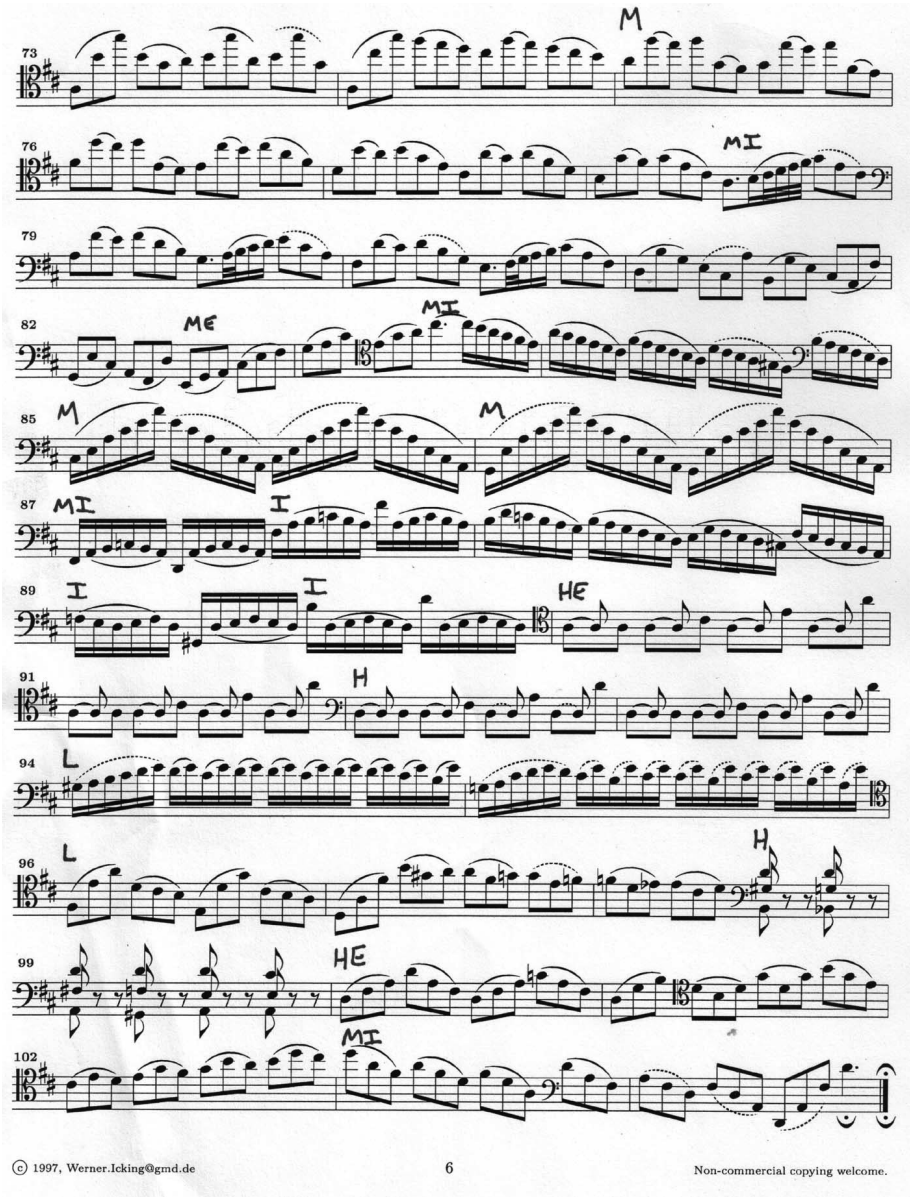
Appendix 1: Score showing the location of expressive performance cues (E), interpretive performance cues (I), harmonic section boundaries (H), melodic subsection boundaries (M) and additional subsection boundaries (L)

Score reprinted courtesy of WIMA: Werner Icking Music Archive http://icking-music-archive.org/







Appendix 2: Regression coefficients (unadjusted) for the effects of musical structure, performance cues and technical difficulties on the number of repeats, starts and stops in each practice session set, with R^2 and 1st order autocorrelations (positive values indicate more repetitions, starts or stops in half bars containing features or cues represented by the predictor variable)

Starts

Learning phase	1. Initial learning					2. First re-learning						3. Second re-learning		
Stage	1. Explore		2. Smooth out	3. Listen		4. Rework			5. Prepare performance					
Type of practice	section	section	integrate	section	integrate	section	integrate	section	integrate	integrate	integrate	integrate	integrate	integrate
Session set	1–10	11–14	15–16	17–20	21–26	27–30	31–32	33–35	36–47	54–57	58–67	68–69	70–72	73–75
Structural cues														
Expressive/sections	8.97***	3.3***	0.52	2.01*	1.06	2.41*	1.22***	5.71**	3.16**	3.27*	0.69	3.39**	1.98	–0.71
Subsections	6.56***	2.33***	0.95***	2.18***	2.34**	1.2*	–0.1	0.5	1.21*	1.61	1.76	0.94	5.06*	2.64***
Switches	4.34	1.29	–0.62	–0.81	–0.53	2.69*	0.01	6.38*	–1.93	–1.54	0.3	–0.05	–2.03	0.99
Performance cues														
Interpretive	3.97*	0.77	0.02	0.19	0.36	0.15	0.02	5.06**	0.27	4.22***	4.27*	0.56	–3.21	–0.63
Intonation	–0.22	–0.11	–0.27	–0.49	1.02	0.19	0.21	2.62*	–0.42	–0.46	0.52	–0.7	–1.48	0.33
Basic: left hand	0.24	0.02	0.02	0.5*	–0.1	0.56*	0.18*	1.17*	0.03	0.42	0.81	0.09	2.2**	0.29
Basic: right hand	–0.31	0.21	0.29	0.77	1.66**	1.1**	0.05	–0.91	–0.02	–1.31*	–0.02	0.32	2.08	–0.06
Interpretation														
Dynamics	1.09**	0.26	0.01	–0.05	–0.12	–0.16	–0.09	0	–0.04	–0.1	–0.23	–0.13	0.03	0.21
Sound quality	1.25	–0.01	0.12	0.7	–0.17	0.39	–0.35	2.04	2.36***	2.88**	1.24	–0.36	–0.55	1.96*
Intonation	2.13	0.6	0.01	–0.39	1.67*	–0.76	–0.43*	–0.41	0.91	2.83***	–0.46	0.61	0.83	0.14
Phrasing	2.14*	0.88**	0.27	0.3	1.44*	0.3	0.35*	1.86*	0.7	0.53	2.88**	0.2	–0.87	0.77
Basic technique														
Hand position	3.53*	0.4	0.25	0.58	–1.09	0.72	–0.1	–1.27	1.31*	–0.54	0.53	0.2	0.59	–0.38
Fingering	0.42	–0.06	0.11	0.44	1*	0.72*	0.24*	0.08	0.23	0.54	–0.03	0.05	1.44	0.59
Bowing/change string	0.94	0.33	–0.07	–0.08	0.42	0	0.16	0.47	0.3	0.4	0.85	0.22	0.1	0.27
Technical difficulty	1.92	0.42	0.32	0.8	2.01*	0.73	–0.12	1.97	0.76	0.83	7.78***	1.39*	4.18*	2.77***
R^2	**0.47**	**0.46**	**0.26**	**0.33**	**0.31**	**0.33**	**0.18**	**0.27**	**0.27**	**0.27**	**0.31**	**0.16**	**0.22**	**0.23**
Autocorrelation	**–0.09**	**–0.14**	**–0.02**	**–0.01**	**0.05**	**0.02**	**0.17**	**0.21**	**0.29**	**0.31**	**0.19**	**0.14**	**0.05**	**0.23**

Stops

Learning phase	1. Initial learning					2. First re-learning						3. Second re-learning		
Stage	1. Explore		2. Smooth out		3. Listen	4. Rework			5. Prepare performance					
Type of practice	section	section	integrate	section	integrate	section	integrate	section	integrate	integrate	integrate	integrate	integrate	integrate
Session set	1–10	11–14	15–16	17–20	21–26	27–30	31–32	33–35	36–47	54–57	58–67	68–69	70–72	73–75
Structural cues														
Expressive/sections	3.76*	2.98***	0.88*	1.84**	0.58	2.45**	0.7	3.21	1.01	2.25	2.31	0.85	1.92	–0.15
Subsections	3.56***	0.3	0.64**	1.1**	1.47*	0.62	0.1	1.62	0.19	1.65	2.02	1.09	4.02*	2.39***
Switches	10.95***	1.45	0.91*	1.21	–0.23	2.63**	0.06	4.28	1.69	0.68	2.62	1.36	3.14	0.53
Performance cues														
Interpretive	1.47	0.94	–0.04	0.9	0.77	0.49	0.29	6.36***	1.48*	2.65*	3.93**	0.41	–1.93	–0.47
Intonation	0.14	0.11	–0.25	–0.1	1.15	–0.35	0.23	3.24**	0.51	0.68	3.23***	0.64	1.34	1.39*
Basic: left hand	0.32	0.24	0.13	0.67***	0.15	0.9***	0.24*	1.5**	0.29	0.55	0.62	0.28	2.69***	0.44
Basic: right hand	–1.03	–0.12	–0.22	0.28	1.35**	0.46	–0.08	–1.84*	–0.64	–1.71**	–0.1	0.09	1.62	–0.26
Interpretation														
Dynamics	0.85**	0.22*	–0.01	–0.1	–0.14	–0.28*	–0.12	–0.32	0	–0.12	–0.36	–0.13	0.29	0.13
Sound quality	2.09	1.05*	0.49*	0.17	–0.09	0.21	–0.23	1.9	3.78***	3.52***	3.11*	0.32	0.33	2.22**
Intonation	1.84*	–0.04	–0.05	–1.19***	1.57**	–1.05**	–0.37	–1.94	–0.56	2.46***	–2.22*	–0.06	–0.88	–1.03
Phrasing	0.73	0.59*	0.21	0.07	0.96*	–0.4	0.17	0.42	–0.03	–0.4	–0.08	–0.23	–2.27*	0.02
Basic technique														
Hand position	1.59	0.79*	0.1	0.24	–1.08	0.63	–0.1	–1.22	0.28	–1.49	–0.07	–0.7	–0.46	–0.73
Fingering	0.03	–0.13	–0.13	0.52*	0.46	0.46	0.11	–0.63	0.59*	–0.5	–0.25	–0.4	–0.04	0.3
Bowing/change string	0.64	0.59***	0.18*	–0.09	0.27	0.2	0.39***	0.81	0.65**	0.65	0.54	–0.07	–0.02	0.11
Technical difficulty	1.39	0.05	0.4*	0.65	1.7**	0.08	–0.21	1.97	0.19	2.33**	5.62***	2.01***	7.05***	3.09***
R^2	**0.45**	**0.36**	**0.27**	**0.35**	**0.31**	**0.34**	**0.15**	**0.28**	**0.25**	**0.27**	**0.36**	**0.16**	**0.33**	**0.32**
Autocorrelation	**0.18**	**–0.04**	**–0.10**	**0.10**	**0.22**	**0.16**	**0.04**	**0.18**	**0.27**	**0.18**	**0.16**	**0.10**	**0.20**	**0.13**

(continued)

Appendix 2 continued

Repeats

Learning phase	1. Initial learning					2. First re-learning						3. Second re-learning		
Stage	1. Explore		2. Smooth out		3. Listen	4. Rework			5. Prepare performance					
Type of practice	section	section	integrate	section	integrate	section	integrate	section	integrate	integrate	integrate	integrate	integrate	integrate
Session set	1–10	11–14	15–16	17–20	21–26	27–30	31–32	33–35	36–47	54–57	58–67	68–69	70–72	73–75
Structural cues														
Expressive/sections	5.35	1.47	0.97	1.72	2.23	4.01*	1.39	5.19	2.57	2.49	2.41	3.7*	2.64	–1.21
Subsections	1.03	0.94	0.76	1.36	1.53	–0.36	–0.15	–0.98	–0.79	1.96	1.86	1.04	5.99*	2.63*
Switches	7.06	2.63	0.61	0.02	–0.97	4.63*	–0.04	10.41*	–0.53	–2.93	2.68	1.73	0.26	2.07
Performance cues														
Interpretive	8.88*	–0.28	0.91	2.75*	4.02*	1.43	0.05	7.69**	3.15	4.18	9.38**	1.3	–1.37	–1.21
Intonation	–1.55	–0.51	–1.04*	–1.99*	1.47	1.43	–0.15	6.35**	–1.39	–0.09	9.52***	–0.57	2.19	6.21***
Basic: left hand	–1.81	–0.93*	0.28	1.29***	0.22	1.64***	0.29	1.74	–0.17	–0.05	1.72	0.83	4.28***	0.21
Basic: right hand	–4.78*	–0.69	0.48	0.5	0.36	1.95**	–0.11	–1.7	–2.44*	–3.08*	1.18	–0.08	1.84	0.58
Interpretation														
Dynamics	3.76***	0.68*	0.04	–0.07	0.49	–0.76*	–0.13	–0.67	0.56	0.01	–1.8**	–0.28	–0.21	–0.04
Sound quality	15.68***	0.75	1.01	4.74***	–1.81	1.99	–1.08*	7.72**	12.19***	11.1***	6.05*	–0.46	0.98	5.41***
Intonation	10.3***	1.39	–0.32	–0.19	6***	–2.03*	–0.75*	–2.83	4.23***	10.29***	–5.87**	1.52	1.2	–2.91*
Phrasing	2.9	1.98**	–0.38	–0.75	0.15	0.77	0.42	1.92	1.4	–0.56	–0.12	–1.24	–4.64*	–0.32
Basic technique														
Hand position	14.7***	4.98***	1.3**	1.13	–3.95**	3.32**	–0.12	0.46	4.84**	–1.55	–3.59	–2.08	–5.94*	–3.08*
Fingering	–0.47	–1*	–0.06	0.7	1.55*	0.1	0.27	–0.26	0.06	–0.29	–0.02	–1.08	0.39	1.65*
Bowing/change string	3.28*	0.82*	0.14	0.53	0.82	–0.06	0.53**	1.63	1.33*	1.41	1.13	0.57	0.15	1.21*
Technical difficulty	1.21	–0.37	0.93*	1.75*	3.52**	0.44	–0.59	3.39	1.43	4.18*	15.03***	5.07***	12.77***	5.37***
R^2	**0.38**	**0.31**	**0.24**	**0.35**	**0.32**	**0.34**	**0.12**	**0.22**	**0.35**	**0.31**	**0.43**	**0.23**	**0.33**	**0.32**
Autocorrelation	**0.69**	**0.67**	**0.65**	**0.62**	**0.61**	**0.67**	**0.59**	**0.73**	**0.67**	**0.73**	**0.63**	**0.57**	**0.46**	**0.62**

***$p < .001$, **$p < .01$, *$p < .05$