Practicing perfection: How concert soloists prepare for performance*

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Abstract: Musical performances by concert soloists in the Western classical tradition are normally memorized but there is little agreement between musicians about how this is done. To find out, we have studied concert soloists preparing new works for public performance. The musicians' reports about their musical decisions provide the key to understanding what they are doing in practice. Practice, in turn, provides a window into the musicians' problem solving strategies. Combining musicians' subjective reports with the objective record of what they do in practice and performance provides insight into how they memorize. Performers have a mental map of the piece in mind as they perform that tells them where they are and what comes next — a series of landmarks, hierarchically organized by the sections and subsections of the music. The musician attends to these *performance cues* in order to ensure that the performance unfolds as planned. Performance cues are established by thinking about a particular feature of the music during practice so that it later comes to mind automatically. Performance cues help the soloist consciously monitor and control the rapid, automatic actions of playing, while adjusting to the needs of the moment.

The skills involved in solo performance in the Western concert tradition push human mental and physical capabilities to their limits. To reach world-class level, the musician must put in 10-20 years of training and 20,000 hours of practice (Ericsson, Krampe & Tesch-Römer, 1998). Once mastered, skills

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must be maintained by continued, regular hours in the practice studio (Krampe & Ericsson, 1996). The same is true of other fields, such as medicine and physics, but music is unusual in that much of what musicians do in those long hours of practice can be easily observed. The musician's decision making is directly reflected in the moment-by-moment stops, starts, and repetitions that are typical of the practice of an experienced musician.

Musicians have a 180-year tradition of performing from memory. Performing from memory was popularized by Paganini, Clara Schuman, and Franz Liszt in the 1820's and 1830's, when these musicians established their reputations as pre-eminent virtuosi by playing entire recital programs without a score. While they may not have been the first to perform from memory in public, they were largely responsible for overcoming public resistance to the practice which was initially seen as arrogant showmanship that was disrespectful to the composer. Today, memorization is seen as a desirable badge of thorough preparation (Williamon, 1999).

It might be expected that this long tradition of performing from memory would have produced a pedagogical tradition that trained young musicians in how to memorize. This has not happened. Instead, memorization is commonly viewed as a highly individual and idiosyncratic process; it is up to each person to find his or her own path. The lack of systematization is evident in the conflicting claims that musicians make about memorization. On the one hand, musicians often describe memorization as something that "just happens" (André-Michel Schub), "a subconscious process" (Harold Bauer), that is "very simple" (Walter Gieseking). On the other hand, when Jorge Bolet boasts in an interview that he memorized Liszt's *Mephisto Waltz* in 75 minutes, he seems to contradict his claim in the same interview that "it's like breathing…memorizing to me is just that natural" (Noyle, 1987, p. 52). If memorization is so easy and automatic, why does he boast about it? Similarly, why did Alexandre Borowski bother to mention to an interviewer that he had memorized "Balakireff's *Islamey.* …the most difficult piece ever written… in 5 days". Or why did Myra Hess describe herself as "blessed naturally with an excellent memory". These statements suggest that memorization is not "just like breathing". John Browning probably comes closest to the truth when he said, "I don't care what anybody says, every performer…always thinks about the possibility of memory slips. Everybody has to work at memorizing". (All quotes are cited in Chaffin, Imreh & Crawford, 2002, Ch. 3).

These conflicting points of view reflect the fact that performance calls on two different types of memory organization, each with very different

properties. On the one hand, there is the memory that develops easily and spontaneously while learning a new piece. We will call this type of memory "*associative chaining*", because each passage cues the memory of what comes next in a chain. For example, when once we have begun to sing "happy birthday", each passage of the song evokes the next from memory like the links of a chain. This is the kind of memory that Jorge Bolet surely had in mind when he said that memory was like breathing. Associative chains form spontaneously and easily as a result of playing or singing and the resulting memories are surprisingly accurate, at least for music and verse (Rubin, 2006).

Associative chains have two important limitations, however, when it comes to performing from memory. First, they are unreliable. They depend on conditions being the same each time. Any change in internal state or external conditions can weaken a link. Since public performance involves large changes, both internal and external, from the conditions present during practice, associate chains are liable to fail when they are most needed — on the public stage. Second, the only way to reach any link in the chain is by starting at the beginning. If memory fails during performance, the only option is to start again at the beginning. Besides being deeply embarrassing, the musician also runs the risk that memory will fail again in the same place.

The remedy is to develop a different kind of memory organization; one that makes it possible to start at other places, in addition to the beginning. We will call this "*content addressable*" memory because it is accessed or addressed by thinking about its contents. For example, the start of "Happy Birthday" is content addressable. We simply think, "Happy Birthday" and the beginning of the tune comes to mind. The name acts as a retrieval cue. For most of us, however, the rest of the song is not content addressable but must be reached by serial chaining from the beginning. For example, most people cannot immediately think of the last line; they have to start at the beginning and run through the song until they get there. Once there, however, it is simple enough to make the last line content addressable. Simply think, "Last line", and mentally rehearse that line. Do this a couple of times to strengthen the association. "Last line of Happy Birthday" is now a retrieval cue providing direct access to this memory. Thinking of it will now activate the relevant memory, allowing you to bring it to mind directly, whenever you want. Unless, of course, you forget!

The advantage of content addressable memory is that it permits recovery from memory slips. A performer can jump to the next retrieval cue and continue the performance. The drawback is the effort required. Setting up

the retrieval cue is not hard, but then it must be practiced to make it rapid and reliable. This is what most people mean by "memorization". There is also another drawback. Content addressable memory involves thinking about what you are doing. Thinking about highly practiced motor skills is a sure way to disrupt them. In athletics, this is called "choking" (Beilock & Carr, 2001). To think about a complex skill without choking takes practice. Memory based on associative chaining develops quickly and easily for many people. Developing reliable, content addressable access to that memory, however, is a slower and more deliberate process that requires extended practice.

Here is how pianist Gabriela Imreh described the process of integrating the two types of memory; she was talking about her learning of J.S. Bach's *Italian Concerto (Presto):*

> *"My fingers were playing the notes just fine. The practice I needed was in my head. I had to learn to keep track of where I was. It was a matter of learning exactly what I needed to be thinking of as I played, and at exactly what point so that as I approached a switching point I would automatically think about where I was, and which way the switch would go"* (Chaffin et al., 2002, p. 224).

What the pianist needed to be thinking of as she played were memory retrieval cues that provided content addressable access to her memory for the piece. We call these "*performance cues"*. Performance cues are mental landmarks that an experienced musician attends to during performance, thoroughly rehearsed during practice so that they come to mind automatically and effortlessly as the piece unfolds, eliciting the highly practiced movements of fingers, hands, and arms. Performance cues become an integral part of the performance and provide a means of consciously monitoring and controlling the rapid, automatic actions of the hands.

There are different types of performance cues. S*tructural* cues are critical places in the formal structure of the music, such as section boundaries, where musical material changes, and *switches* where the same theme or pattern repeats at different points in the piece and might be confused. *Expressive* cues represent musical feelings to be conveyed to the audience, e.g., surprise or excitement. *Interpretive* cues are places where some aspect of interpretation requires attention, e.g., a change of tempo or dynamics. *Basic* cues represent the critical details of technique that must be executed exactly for the performance to unfold as intended, e.g., the use of a particular fingering in order to set the hand up for what follows. Other ways of classifying the different types of cues are possible, but this classification has been adequate for the studies conducted so far.

Longitudinal Case Studies

We have tracked the development of performance cues as musicians prepared new works for public performance. In these studies, experienced soloists recorded their practice of a new work from the first time they sat down to play through the piece until it they performed it in public. Each study was a collaboration between a musician and a psychologist. The musician decided which piece to learn and reported every decision made during practice about basic technique, interpretation, and performance. The psychologist provided the tools to relate these reports to the musician's practice and performance of the piece. The musician's first-person perspective and the psychologist's third-person perspective were given equal weight in understanding the learning process. While experienced musicians can provide detailed and insightful self-reports about their practice and memorization strategies (Hallam, 1995), the validity of any retrospective self-report is open to question (Ericsson & Simon, 1980). The behavioral data provided a check. Usually behavior and report agreed, but sometimes they did not. In these cases, the musicians were surprised and learned something new about themselves. When self-report and observation are combined in this way, musicians' practice provides a natural laboratory for studying the complex mental and motor skills involved in performance (Chaffin & Imreh, 2001).

In the first of these studies, pianist Gabriela Imreh learned J.S. Bach's *Italian Concerto (Presto)* in 33 hours of practice over a period of 9 months for a CD recording (Chaffin et al., 2002). At the same time, she also learned *Clair de Lune* by Claude Debussy in 4¾ hours to play as an encore piece (Chaffin, 2007). In other studies a soprano and conductor prepared Stravinski's *Cantata (Ricercar)* for soloists, choir, and orchestra (Ginsborg, Chaffin & Nicholson, 2006) in 8½ hours of practice and rehearsal, and a jazz pianist learned Hank Mobley's *Funk in deep freeze* (Noice, Jeffrey, Noice & Chaffin, 2008). Here we will describe the most extensive of these studies in which cellist Tânia Lisboa (the second author of this paper) learned the *Prelude* from J.S. Bach's *Suite No. 6* for solo cello and gave ten public performances over a period of more than three years (Chaffin, Lisboa, Logan & Begosh, 2009).

First, we will describe the phases and stages of the learning process. Second, we will describe how the locations of starts and stops during practice indicated which aspects of the music she was attending to. Third, we will describe her spontaneous comments to the camera during practice, focusing

on one passage where she deliberately created performance cues to solve a memory problem. Fourth, the cellist wrote out the score from memory after a 10-month interval of not playing the piece. If performance cues are landmarks in memory, as we have suggested, then they should be remembered better than the rest of the piece. Finally we will look at bar-to-bar fluctuations in tempo during performance for evidence that the cellist thought about performance cues as she played. Hesitations in early practice performances from memory showed that performance cues were used for memory retrieval. Fluctuations in tempo at expressive and interpretive cues during polished performances suggested that performance cues correspond to the musical gestures embodying the cellist's musical interpretation.

Learning the *Prelude*

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 3½ years 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 38¼ hours 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 almost 33 hours. During practice the cellist talked to the camera periodically about what she was doing.

Practice occurred in three main learning periods separated by two long breaks of 8 and 18 months respectively: (1) initial learning, consisting of 26 sessions, totaling 8½ hours, over 3 months, (2) 1st re-learning consisting of 41 sessions, totaling 25½ hours, over 4 months, and (3) 2nd re-learning consisting of 8 sessions, totaling 4¼ hours, over one month (see Figure 1). There were additional shorter breaks of 1-4 months within learning periods 1 and 2. Eight public performances took place towards the end of learning period 2, two more at the end of learning period 3.

Stages of learning & Types of Practice

The cellist identified five stages in her learning: Explore, smooth out, listen, re-work technique, and prepare performance. These stages correspond fairly 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*),

re-work technique (*work on technical difficulties*), prepare performance (*trial rehearsals*). We will briefly describe each stage.

Exploration (sessions 1-14). The cellist began her exploration of the expressive and technical possibilities of the piece by sight-reading through it. She then focused on successive sections in each session until she reached the end of the piece in session 10. At this point, she was obliged to interrupt her practice while the camera was repaired. When she returned to the piece after a 6-week break, she worked through it again, section-by-section, in sessions 11-14.

Smoothing out (sessions 15-20). In session 15, the cellist prepared to play through the entire piece from memory, which she did for the first time at the end of the session. The cellist said before she started playing from memory, "*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.

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 8 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."*

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). At this point, the cellist began to prepare 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 2nd learning period to an end. After an 18-month break, she

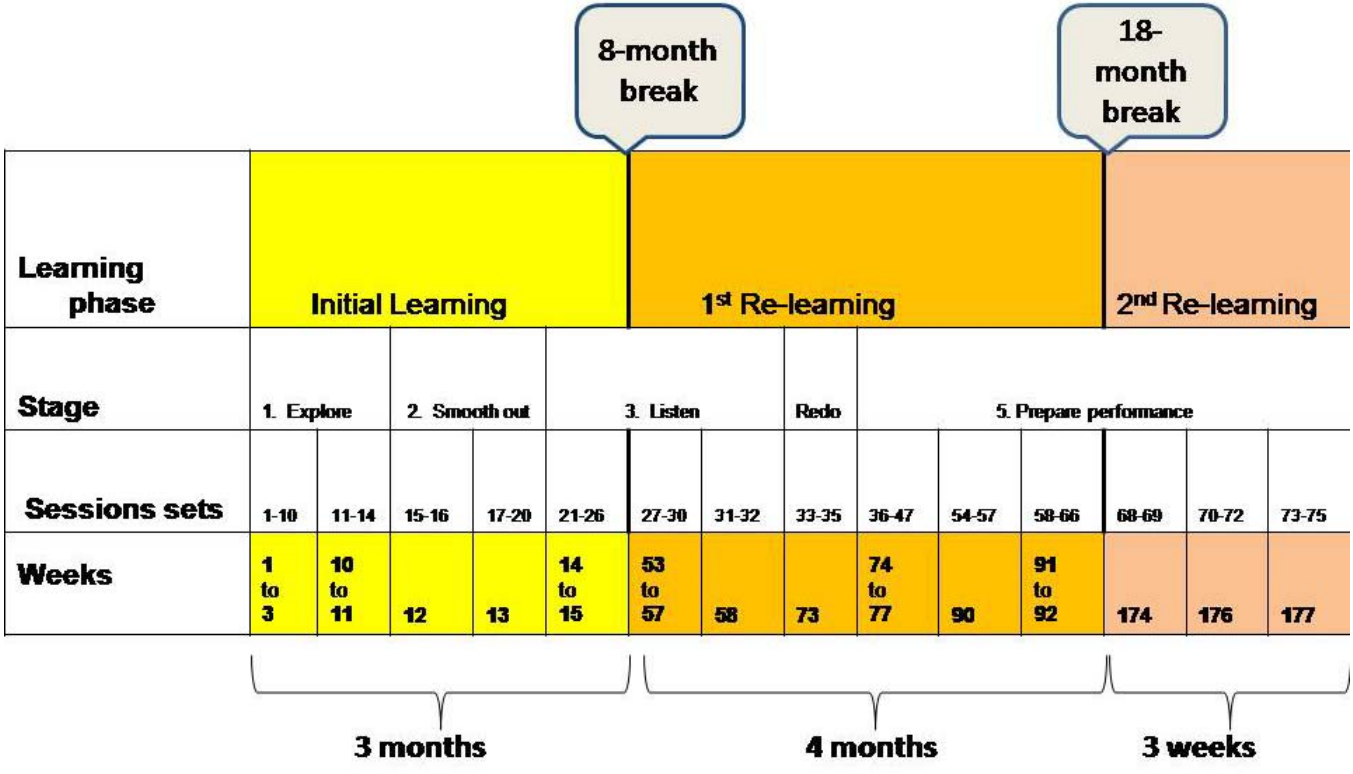

Figure 1: Phases, Stages, and Breaks in Learning

learned the piece again for another public performance given in connection with a report on the research at a psychology conference (Lisboa, 2006).

Two types of practice. 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 2 shows the 50 minutes of practice in session 6. 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 subsections 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 3 shows the first session devoted to integrative practice, session 15. Practice was still organized by subsections, but extended over the entire piece. The cellist was putting together the subsections in preparation for the first performance from memory, which took place at the end of the session — represented by the solid horizontal line at the top of Figure 3.

Relating practice to reports of performance cues

Practice started and stopped in some places, but not others (see Figures 2 & 3). What was special about these places? The arrows in Figure 3 provide an answer, for session 15. Playing started at the beginnings of subsections; not all the time, but often enough to show that she was thinking about them. This session is particularly interesting because the cellist was getting ready to play from memory. As she did so, the melodically-based subsections provided landmarks for her practice. We will show that they were also landmarks in her memory.

How do we know that the places marked in Figure 3 are the subsections boundaries as understood by the cellist? Because she marked them on a copy of the score. She did this at the end of learning period 2, and around the same time she marked all of the other aspects of the music that she had been thinking about as she practiced and performed. Figure 4 lists the different reports. Figure 5 provides examples (for bars 65-70) from two reports: decisions about bowing (top panel) and performance cues for bowing (bottom panel). The cellist used arrows to indicate places where she thought about bowing. These are highlighted in the figure for easier identification. Figure 4 also illustrates the relationship between decisions about bowing and basic performance cues for bowing. There were a lot of bowing decisions, and many fewer performance cues. With practice, bowing became automatic.

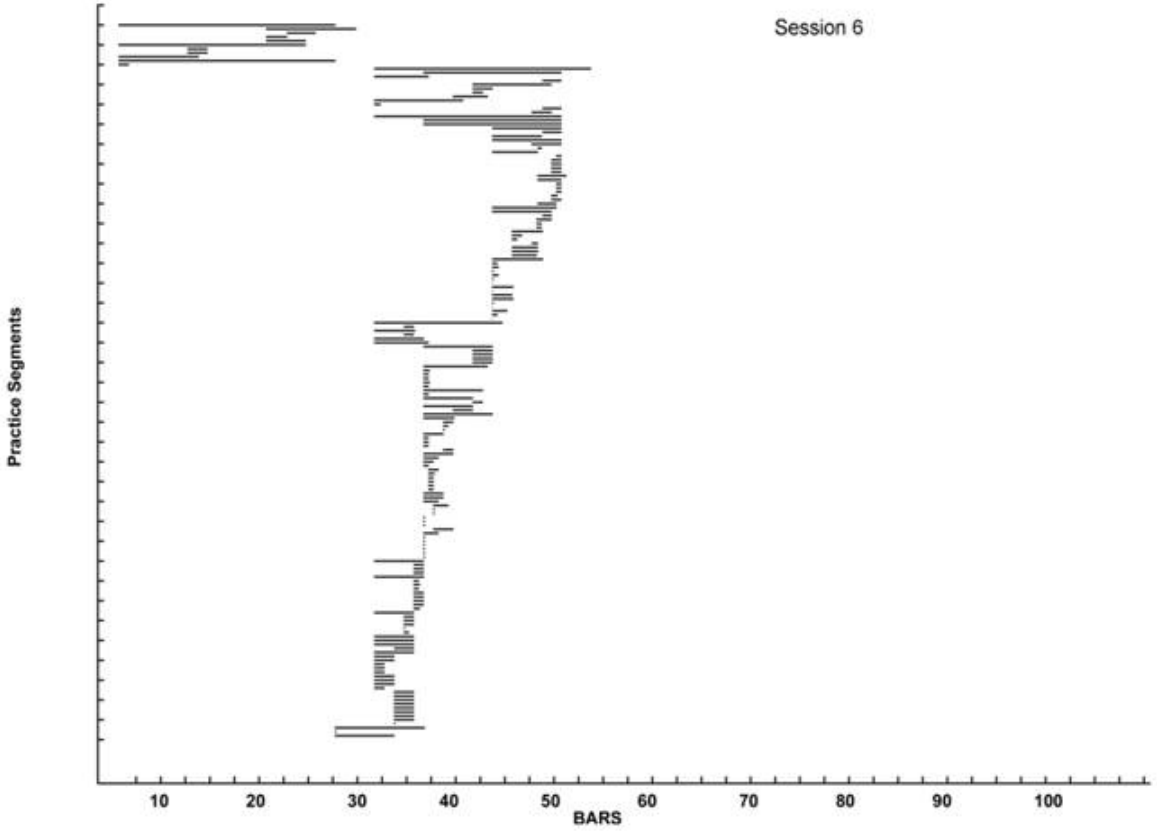

Figure 2: Practice Record for Session 6 Showing Section-by-Section Practice.

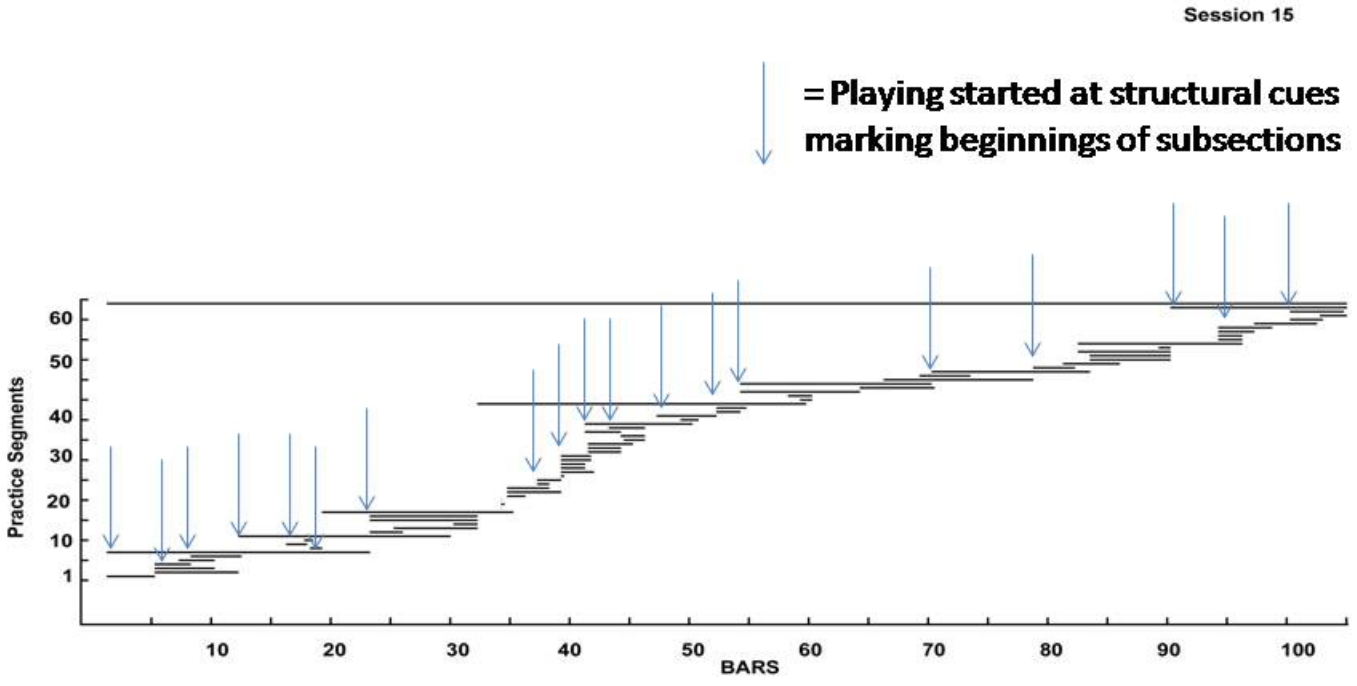

Figure 3: Practice Record for Session 15 showing where Practice Started at Structural Performance Cues Marking Beginnings of Subsections.

However, the cellist decided that she needed to think about the bowing in some places to make sure that the performance stayed on track. These became performance cues. For example, she discovered that she was confusing bars 68-69 with the very similar passage in bars 66-67. To help her distinguish the two passages, she decided to attend to bowing in bars 68-69. With more practice, bowing became a performance cue as the memory of the direction of bowing came to mind automatically as she played.

In Figure 3 one can readily see that playing often started at the beginnings of subsections. This relationship was not limited to sessions 15, or to this kind of report. We used regression analysis to examine the relationship of all 33 hours of recorded practice to each of the 13 aspects of the music that the cellist reported. The analyses for starts are summarized in Figure 6, showing when practice started at each kind of performance cue.

The cellist practiced performance cues throughout the learning process. They were always on her mind, but not always the same ones. She thought about different types of cues at different times, and in different combinations. Early on, playing started at expressive performance cues and beginnings of subsections. Since expressive cues mostly occurred at the beginnings of the main sections of the musical structure, it seems that the cellist was thinking about the musical "big picture" and organized her practice accordingly. The same thing happened again at the beginning of the 1st and 2nd relearning

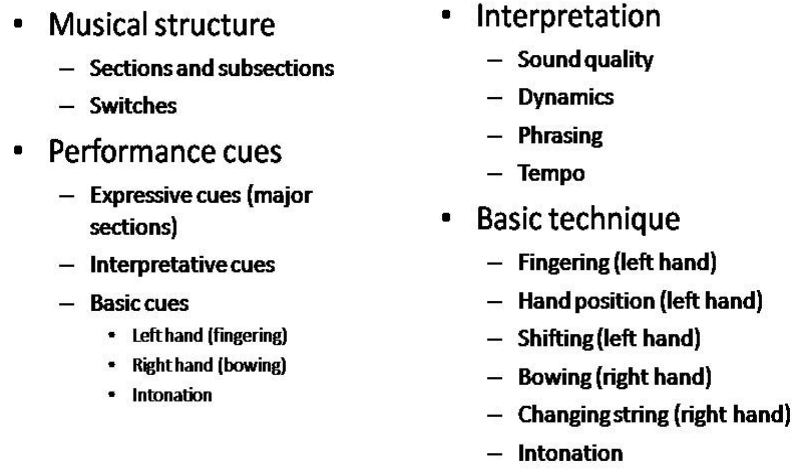

Figure 4: Aspects of the Music that the Cellist Thought about during Practice and Performance and for which She Provided Reports

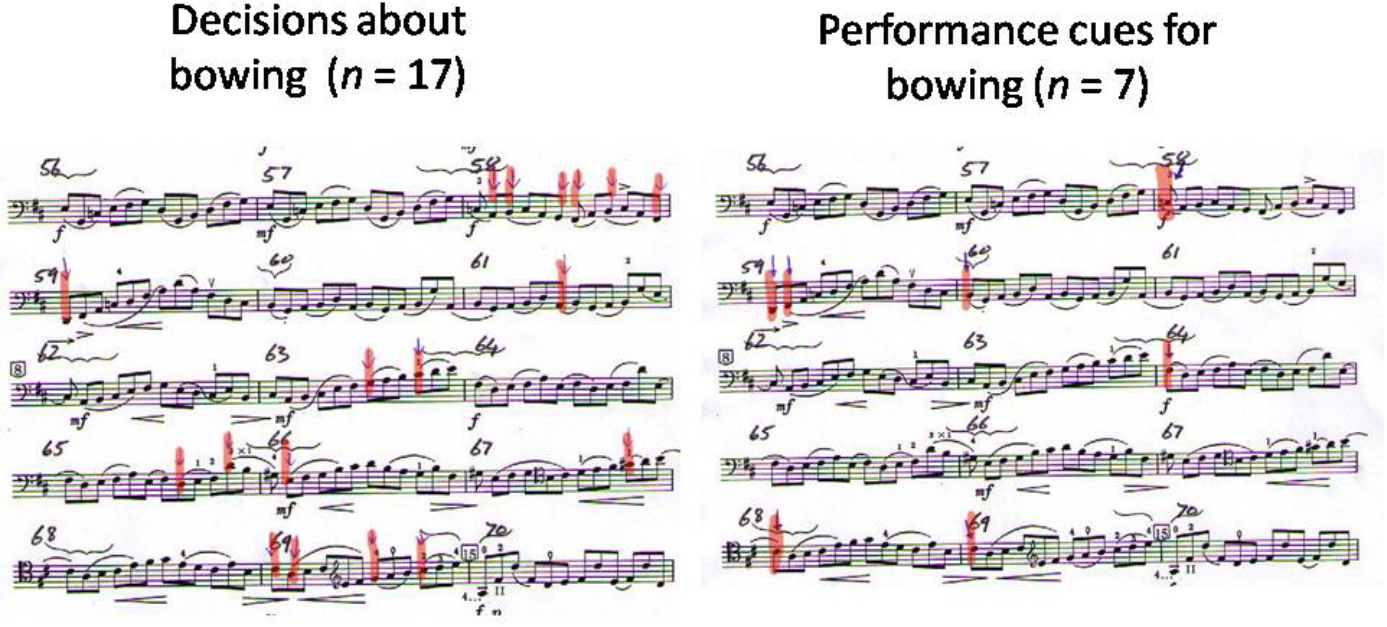

Figure 5: Example from the Cellist's Reports of Bowing Decisions and Performance Cues for Bowing (bars 56-70)

periods – playing started at expressive cues and subsections. Later in each learning period, expressive cues stopped being the main focus and other aspects of the music were used as starting points instead. In the second half of the initial learning period, in the "smoothing-out" stage, playing started at the beginnings of subsections and at bowing cues. In the second half of the 1st relearning period, as she polished her interpretation in preparation for the first public performance, playing started at interpretive and expressive performance cues.

The cellist's concerns changed as practice progressed and are reflected in where she chose to start. By starting at performance cues, she established the links between thought and action needed to develop a content-addressable memory. By doing so throughout the learning process, she developed the speed and automaticity needed for the cues to work reliably under the pressures of the concert stage.

Comments about performance cues

The cellist's comments during practice provide further support for the idea that performance cues helped her to remember. We will describe comments about the memory problem in bars 68-69 that we referred to earlier (on page 122). The cellist first noted the potential for a problem in session 8, "*It's [bars 68-69] exactly the same pattern but…a [4th] higher [as bars 66-67)"*. She commented on this 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…."* Her comment on session 33 explains why cues were needed, to help her remember. Figure 5 shows the up-bows reported as performance cues in bars 68 and 69 almost two years later.

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 7). The comment explains what this means: Thinking about the crescendo on the up-bow helped her keep the two passages straight. We saw in the previous section that interpretive cues were practiced in sessions 33-35 (see Figure 6).

Learning phase	Initial Learning					1st Re-learning						2nd Re-learning		
Stage	1. Explore		2. Smooth out		3. Listen			Redo	5. Prepare performance					
Sessions	1-10	11-14	15-16	17-20	21-26	27-30	31-32	33-35	36-47	54-57	58-66	68-69	70-72	73-75
Expressive cues	X	X				X	X	X	X	X		X		
Subsections	X	X	X	X	X	X							X	X
Basic Cues (bowing)					X	X								
Interpretive cues								X		X	X			

Figure 6: Sessions Where Playing Started at Performance Cues (marked x)

This comment from session 33 shows one reason for this practice — to help with memory.

This was not the end of the story. In practice session 44, the day before the first public performance, the cellist had a memory failure in bar 68 during a practice performance. She stopped, swore, and went back for another try. Although she made no further comment, we know what had happened, because we know the history of this passage. Once again she had confused bars 66-67 and bars 68-69. The two performance cues that she had established (for bowing and dynamics) had let her down. Still more practice was needed to make them function reliably every time.

Recall

Ten months after the end of learning period 2, the cellist wrote 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. Not surprisingly, the cellist's recall showed substantial forgetting; accuracy was 52%.

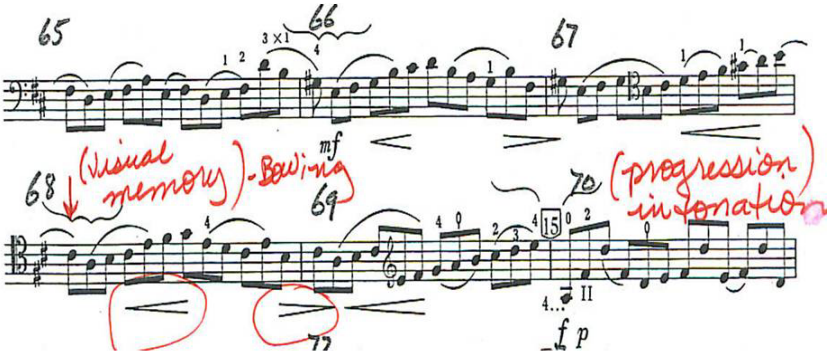

Figure 7: Example from the Cellist's Report of Interpretive Performance Cues (bars 65-70)

We looked for the landmarks in the cellist's memory: places that she remembered better than others. Figure 8 shows the probability of correct recall as a function of position in a subsection (left panel) and position with respect to expressive performance cues (middle panel), and basic performance cues (right panel). The left panel shows that recall was best for the first bar in a subsection and declined for each successive bar that followed – a classic

serial position effect (Raaijmakers & Shiffrin, 1981). The middle panel shows the same pattern for expressive performance cues. Recall was almost perfect in bars containing expressive cues, declined gradually up to the sixth bar, and then dropped sharply in the bars that followed.

The effects for expressive cues and subsections suggest that these were the main landmarks of the cellist's memory. The effects also suggest that expressive cues (mostly at the beginnings of main sections) were more important landmarks than beginnings of subsections, because recall was a lot better at expressive cues. For both sections and subsections, beginnings were remembered better than what followed. Beginnings could be accessed directly by performance cues; they were content addressable. The bars that followed, in contrast, were accessed from the preceding bar by serial cuing. Since there was some possibility of retrieval failure in each successive bar, recall decreased as distance from the performance cue increased. This kind of serial position effect is a normal feature of memory for ordered series (Roediger & Crowder, 1976).

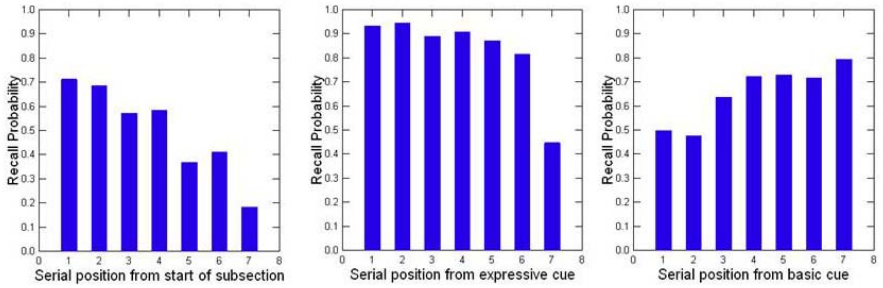

Figure 8: Probability of Correct Recall as a Function of Position following Beginnings of Sub-sections, Expressive Performance Cues, and Basic Performance Cues

The effect of basic performance cues on recall was, however, in the opposite direction. Recall was lower at basic cues and increased as distance from the cue increased. The effect suggests that basic cues worked differently. They did not provide direct, content-addressable memory access. We believe that they were activated by serial cuing and reminded the musician about important details of technique (Chaffin, Logan & Begosh, 2009; Rubin, 2006). In writing out the score from memory the cellist was not performing the relevant actions, and so the memories associated with those actions were less available.

These 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 performance cues and positive serial position effects for basic performance cues. The effects suggest that expressive and structural cues provide content-addressable access to memory, while basic performance cues operate by serial cuing.

Hesitations in practice performances

Hesitations in practice performance provide another way of showing that performance cues are used for memory retrieval. Figure 9 shows the tempo of practice performances measured in half-bars for the entire piece. The left panel shows the mean tempo of the first three practice performances (in sessions 15-18); the right panel shows the mean tempo for seven practice performances late in the learning process, after the initial public performances (in sessions 45-66). There were two pronounced downward spikes in the early performances, representing substantial, momentary slowing. The locations of the downward spikes are marked by arrows in the left panel. The corresponding locations in the right panel of Figure 9 are also marked, but there are no spikes. There was no slowing in the late performances. Because slowing occurred only in the early and not in the late practice performances, it was almost certainly due to hesitation rather than to expressive tempo variation.

Why did the cellist hesitate? Again, her reports provide the answer. At the location of the first spike, the cellist reported a switch – a place where the same pattern repeats at different points in the piece. The switch is the place that the two repetitions begin to diverge. If the musician takes one continuation, she is at one location in the piece. If she takes the other, then she is at a different location. The musician has to chose the right continuation or suddenly find herself switched into an entirely different location in the piece. Performance cues are needed to ensure that the right switch is made. The downward spike in the early performances suggests that the cellist knew that she had to choose but was unsure which path to take. Its absence in the late performances suggests that memory retrieval was now up to speed. The knowledge of how to continue came to mind quickly enough that there was no longer any need to hesitate. The cellist did not report this switch as a performance cue, but these data suggest that it was functioning as one, at least in the early performances.

At the location of the second spike the cellist reported a performance cue for bowing. Earlier, we described how a different example of a bowing cue helping with memory, in bar 68. Here we have another case. The bowing cue apparently helped the cellist to remember since, by the time of the late performances, the hesitation had disappeared. The presence of hesitations in the early practice performances at a switch and a bowing cue suggests that memory retrieval was occurring at these places.

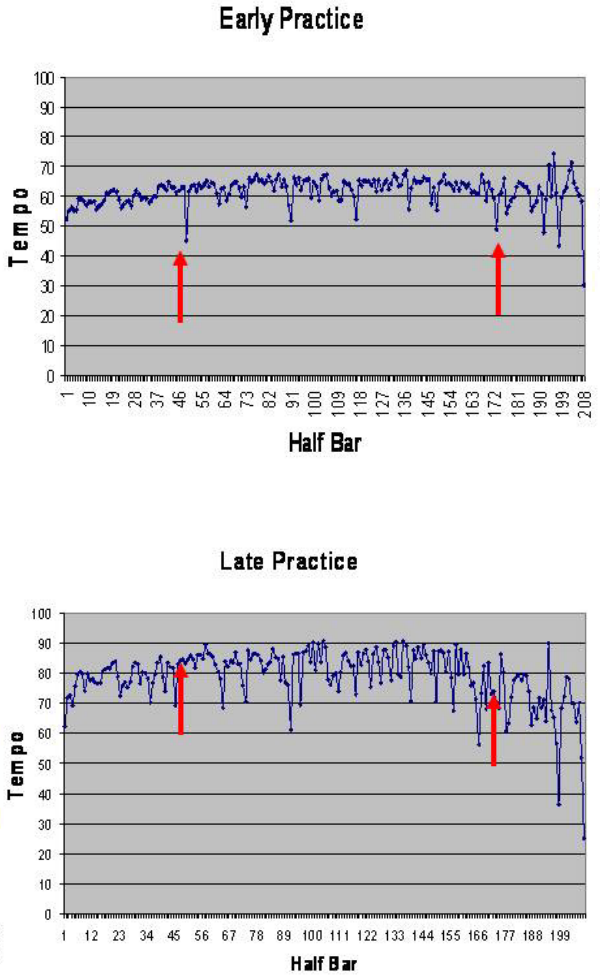

Figure 9: Mean Bar-by-Bar Tempi in Early and Late Practice Performances

Musical gestures in polished performance

Performance cues also play an important role in musical expression. We can see the musical gestures of the cellist's interpretation reflected in the wavelike shape of the tempo profiles in Figure 9, for both early and late performances. The waves are more pronounced and numerous in the late than in the early performances, as would be expected if they reflect musical interpretation. The change reflects the cellist's evolving interpretation. Her musical gestures apparently became more pronounced and better differentiated as preparation of the piece progressed. Again, it is the cellist's reports that provide the key that leads to this understanding.

Figures 10 and 11 show the tempi for the first 90 half-bars of the piece. (The tempi are averages, based on factor analysis of 27 polished performances, all of the public and practice performances between sessions 45 and 68). Figure 10 shows the location of the expressive performance cues reported by the cellist, along with the descriptive labels that she later provided for them, e.g., "flow", "dominant", "calm/melodic". Figure 11 shows the interpretive performance cues reported for the same passage along with their labels, e.g., "sing", "voicing", "growing". In both cases, the cues correspond to troughs between the wave-like shapes of the tempo profile. The cellist was slowing at these points for interpretive effect. The correspondence between the tempo profile and the performance cues suggests that the cues were responsible for the wavelike fluctuations in tempo.

The cellist was very much aware of the musical gestures of her interpretation. She was not, however, aware of the fluctuations in tempo and was surprised when she saw them in the tempo profiles. Her announced intention was to play the piece metronomically, in accordance with Baroque performance practice. From her perspective, the tempo *was* steady. She experienced the dips in tempo at performance cues, evident in Figures 10 and 11, as emphases, rather than as changes in tempo. The same is true when one listens to the performances. The tempo sounds regular; the playing sounds expressive. The fact that expressive variations in tempo occurred at performance cues suggests that the cues played a role in producing the musical gestures responsible (Chaffin, Lemieux & Chen, 2007).

Conclusion

Like other experienced soloists who have been studied (Chaffin & Logan, 2006), the cellist engaged in extended practice of performance cues in order to develop content-addressable access to her memory of the *Prelude.*

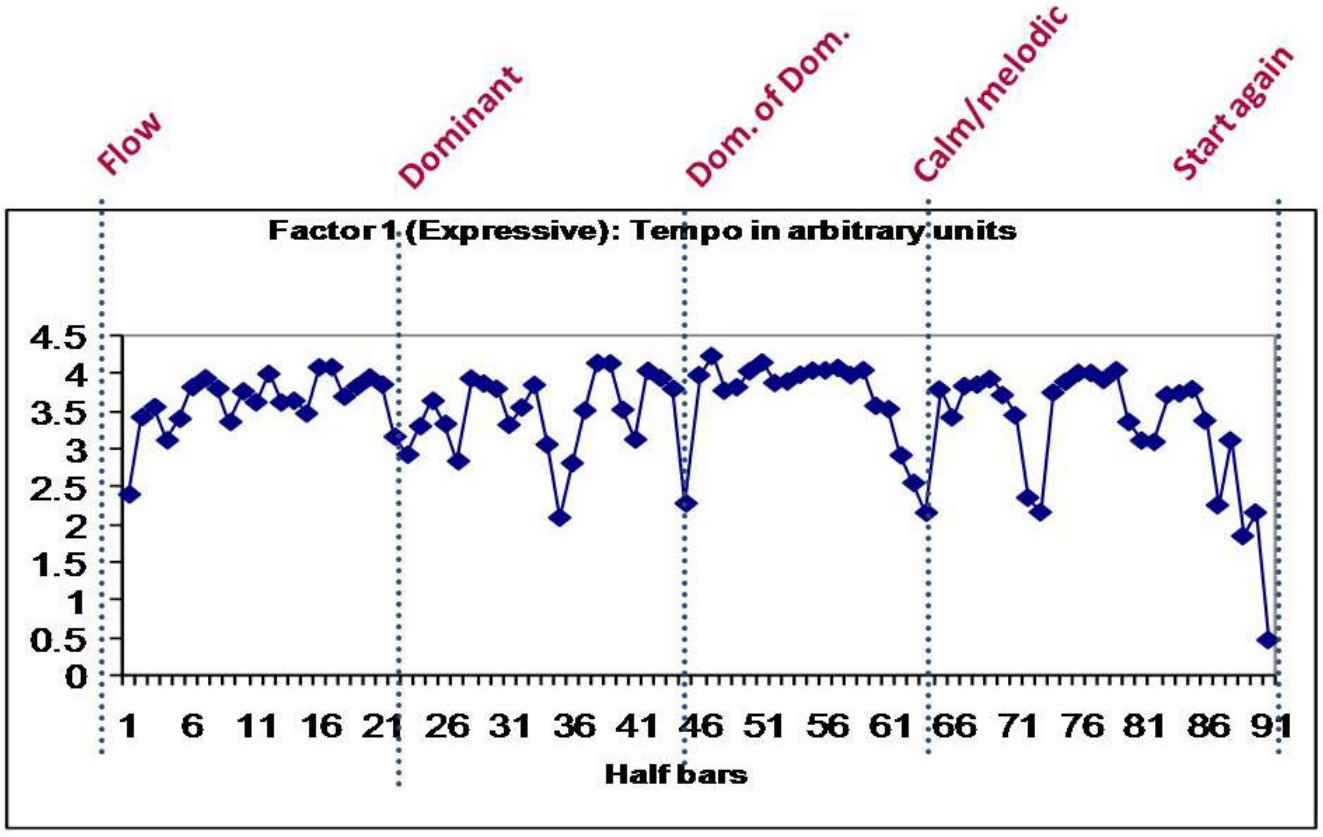

Figure 10: Bar-by-Bar Tempi of Polished Performances Showing the Location of Expressive Performance Cues

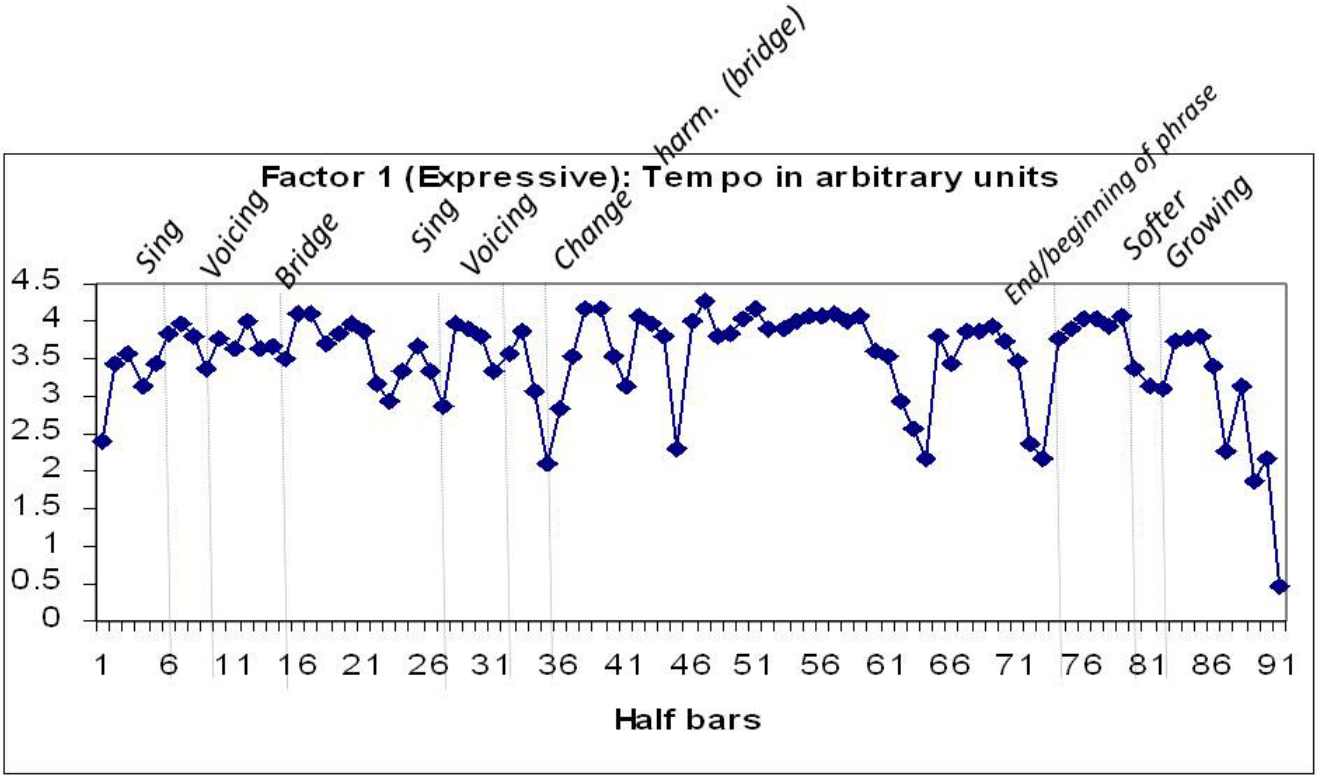

Figure 11: Bar-by-Bar Tempi of Polished Performances Showing the Location of Interpretive Performance Cues

Performance cues provided the mental landmarks that told her what to do as the performance unfolded, reminding her of decisions about technique, interpretation, and expression (Chaffin et al., 2007). The most direct evidence that performance cues played a critical role in memory retrieval came from written recall of the score. Memory was best at expressive cues and subsection boundaries and declined as distance increased. The serial position effects suggested that these were the main landmarks in the cellist's memory. The fact that expressive cues were recalled better than beginnings of subsections suggested, further, that the music was hierarchically organized in her memory, with subsections nested below expressive cues.

Figure 12 summarizes this account, showing a schematic representation of the cellist's memory for the *Prelude* unfolded at the point where she is playing bar 68. The music is organized into sections marked by expressive cues and subsections marked by structural cues. This hierarchical structure provided rapid, content-addressable access to memory for any passage in the piece. Other performance cues embedded in this organization provided reminders of interpretive and technical decisions needed for the performance to unfold as planned (Chaffin et al., 2002, p. 200).

The practice records showed how this memory organization was established. From the outset, the cellist used expressive cues and beginnings of subsections as starting points during practice. In order to start at these places, she had to first think about the music and then start playing. This established a link between the thought and the action. Later, just thinking of the place, e.g. "dominant", was sufficient to bring the relevant passage to mind and to start playing. With further practice, the link became rapid and reliable (Chaffin & Imreh, 2002).

The cellist's practice of performance cues continued long after she was able to play from memory (in session 15). This extended practice was necessary to ensure that memory retrieval would function reliably under the pressures of concert performance. In the early practice performances there were hesitations at performance cues and at switches. With more practice, the hesitations disappeared as retrieval became more reliable. Nevertheless, we caught a memory lapse on tape immediately before the first public performance, in session 44. Extended practice can minimize the likelihood of memory failure, but can never totally eliminate it.

The comments showed how the cellist strategically added performance cues for bowing and dynamics to overcome a specific memory problem. Performance cues have multiple functions. Thinking about bowing and dynamics in bars 68-69 served both to distinguish them from bar 66-67 and

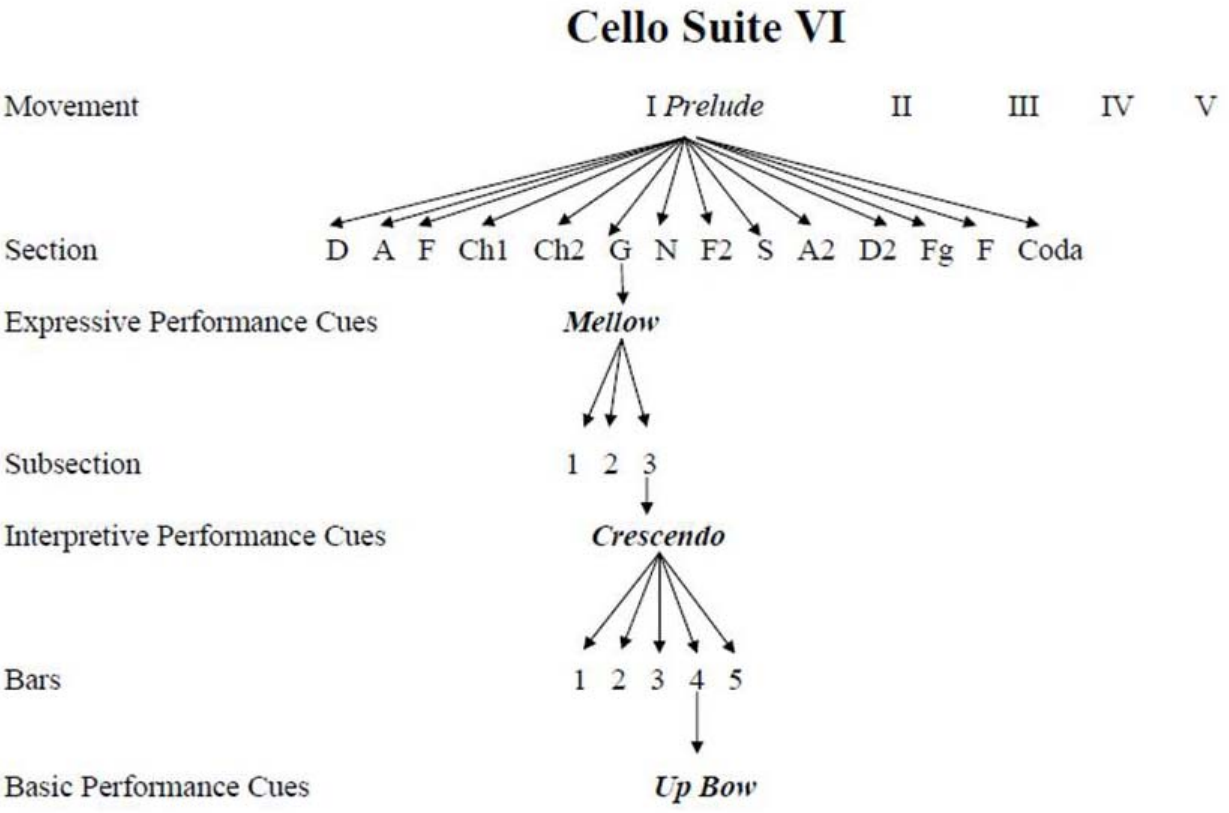

Figure 12: Diagram Representing the Cellist's Memory for the Prelude *while Playing Bar 68 of the* Prelude

to ensure that the crescendos on the up-bow were implemented as planned. Expressive cues, like "calm/melodic", both reminded the cellist of the musical feel of the upcoming passage and also provided content-addressable access in case of a memory failure during performance.

We propose that most experienced performers memorize in much the same way, with only superficial differences due to music, instrument, and learning style. This generalization is based on the consistency across different case studies (Chaffin, 2007; Chaffin & Imreh, 2002; Ginsborg, Chaffin & Nicholson, 2006; Noice et al., 2008) and the consistency between what we see experienced musicians doing in these case studies and general principles of memory (Ericsson & Kintsch, 1995). 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.

We believe that the stages and cycles of practice that we have identified are characteristic of experienced musicians in general. Musicians preparing a piece over an extended period work in bursts separated by long breaks (Chaffin et al., 2002, pp. 98-99), go through similar stages (Chaffin et al., 2002, pp. 100-114; Hallam 1995; Wicinski, 1950, reported in Miklaszewski, 1989), and alternate cycles of section-by-section and integrative practice (Chaffin et al., 2002, pp. 116-119). Like other experts, the cellist began with the musical "big picture", attending to the expressive and structural cues that reflected her "musical image" of the piece, and returning to them at the start of each learning period (Chaffin, Imreh, Lemieux & Chen, 2003; Ginsborg, Chaffin & Nicholson, 2006; Lehmann & Gruber, 2006; Neuhaus, 1973).

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 have described 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 practiced 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 3½ years, provide the most complete description to date of how this is done.

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