

“Pulling Teeth and Torture”: Musical Memory and Problem Solving

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A concert pianist (the second author) videotaped herself learning J.S. Bach's *Italian Concerto (Presto)*, and commented on the problems she encountered as she practised. Approximately two years later the pianist wrote out the first page of the score from memory. The pianist's verbal reports indicated that in the early sessions she identified and memorised the formal structure of the piece, and in the later sessions she practised using this organisation to retrieve the memory cues that controlled her playing. The practice and recall data supported this account. Both were organised by the formal structure of the music. Practice segments were more likely to start and stop at boundaries of the formal structure than at other locations, and recall was higher for the beginnings of sections than for later portions. Like other forms of expert memory, pianistic memory appears to be based on use of a highly practised retrieval scheme which permits rapid retrieval of information from long-term memory.

INTRODUCTION

In the European concert tradition, the practice of playing from memory is a relatively recent development. It began in the second half of the nineteenth century, when Franz Liszt and Clara Schumann created a sensation in the salons and concert halls of Europe by playing without a score. Today, the ability to play from memory is a central feature of the concert soloist's professional competence. The demands placed on memory during a piano performance are remarkable, sometimes requiring the production of over 1000 notes a minute for periods of up to 50 minutes. Not surprisingly, memory and attentional lapses are

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not uncommon. An important part of the artist's preparation of a piece for performance is to develop multiple, flexible retrieval systems that will permit the performance to continue, whatever may go wrong.

Concert artists thus provide a test of the generality of the principles of skilled memory proposed by Chase and Ericsson (1982a) and Ericsson and Kintsch (1995). The study of expert memory has focused primarily on domains involving conceptual knowledge (Ericsson & Oliver, 1989). Musicians, in contrast, rely heavily on motor memory, which can, if permitted, function automatically without conscious control (Sloboda, 1985, p.96). Therefore, pianistic memory may not be subject to the same principles as other types of expert memory. We examine this possibility by describing a self-study of a concert pianist preparing a new piece of music for performance.

Expert Memory

One of the hallmarks of expertise is the ability to memorise with an efficiency that seems beyond the norm (Chase & Simon, 1973). These feats have been explained in terms of three principles of skilled memory: meaningful encoding of novel material, use of a well learned retrieval structure, and rapid retrieval from long-term memory (Chase & Ericsson, 1982a; Ericsson & Kintsch, 1995; Ericsson & Oliver, 1989). According to the first principle, experts' knowledge of their domain of expertise allows them to encode new information in terms of knowledge structures already stored in memory. For a pianist these include chords, scales, arpeggios, phrases, and harmonic progressions, the practice of which forms an important part of every pianist's training. These knowledge structures are built up during the decade or more of training that is required to develop a high level of expertise (Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Römer, 1993). Their presence in semantic memory allows the expert to recognise novel situations as variations of more familiar ones (Anderson, 1983; Ericsson & Kintsch, 1995). As a result, the expert can work with larger chunks of information than the novice (Halpern & Bower, 1982), identify and remember large amounts of information rapidly (Chase & Simon, 1973), and make snap decisions about complex situations (Gobet & Simon, 1996a).

The second principle asserts that expert memory requires a highly practised, hierarchically organised retrieval scheme to provide cues to be associated with the novel information that is memorised at encoding (Ericsson & Oliver, 1989). These cues can be used to retrieve the information when it is needed. For a pianist, the large-scale organisation for a hierarchical retrieval scheme may be provided by the formal structure of a composition. For example, the work we studied, the *Italian Concerto* by J.S. Bach, is divided into three movements. The third, marked *Presto*, is in Italian Rondo form, which typically consists of a theme, *A*, repeated six times, with minor variation, separated by five sections containing different musical material: *A1 B A2 C A3 D A4 E A5 F A6*.

According to the third principle, prolonged practice dramatically increases the speed with which the expert can use the retrieval scheme to access information in long-term memory (Ericsson & Kintsch, 1995). This allows the expert to rely on memory in situations in which most people rely on external aids. If the pianist uses the hierarchical structure of the music in this way, then we would expect to see evidence of extended practice at using the formal structure to guide retrieval.

The Relation of Motor and Conceptual Memory

A difference between the skilled memory of musicians and other experts whose memory has been studied to date is that motor memory appears to be much less important for actors (Intons-Peterson & Smyth, 1987; Ericsson & Oliver, 1989), waiters (Ericsson & Polson, 1988), and mnemonists (Luria, 1968; Thompson, Cowan, & Frieman, 1993) than for pianists. Often, beginning pianists appear to rely almost exclusively on motor memory, perhaps because it can be developed easily and rapidly through simple repetition (Chaffin & Imreh, 1994). This appears to be the source of the classic memory failure scenario of the student recital: the performer falters and cannot continue (Sloboda, 1985, p.91). As the retrieval cues for motor memory are generated by the preceding actions, once the performance stops, there is no way to resume. The embarrassed performer must go back to the beginning and risk repeating the debacle. For this reason, as well as for aesthetic ones, experienced pianists develop other types of memory representation.

A performer who knows where he or she is in the formal structure of a piece can recover from the kind of memory failure just described by jumping forward to a new starting point and continuing to play. Conceptual representation of the formal structure could also provide retrieval cues to elicit the motor performance, as well as allowing the pianist to keep track of where he or she is so that he or she does not inadvertently omit a section. For these reasons, we might expect that a concert pianist would make use of a conceptual representation that would function as a hierarchical retrieval structure of the sort described for other expert memorists.

THE STUDY

The use of the formal structure of a piece to organise practice and aid memory is a standard recommendation of piano pedagogues (Lehrer, 1988; Sandor, 1981; Shockley, 1986). However, there have been no empirical descriptions of the technique. The small number of studies of experienced pianists indicate that they routinely practised pieces they were learning in sections, but this observation is not related to the formal structure of the music or to memorisation (Gruson, 1988; Miklaszewski, 1989, 1995). The present study provides the first report of how an elite pianist memorises.

We observed a concert pianist (the second author) learning the third movement (*Presto*) of the *Italian Concerto* by J.S. Bach. The pianist recorded her practice and, as she worked, commented on what she was doing. She was also interviewed about the learning process and she provided a description of the features of the piece that she planned to think about as she performed. Additionally, more than two years later, the pianist wrote out as much of the first page of the score as she could remember. We examined the pianist's concurrent and retrospective commentary on her practice, the objective record of her practice, and her free recall of the score to determine whether she appeared to use the kind of highly practised, hierarchical retrieval scheme described by Ericsson and Kintsch (1995).

We expected the pianist's commentary on her practice to describe the problems she encountered. We looked for mention of familiar patterns that the pianist recognised in the music, and for identification of its formal structure. Most critically for the proposal that the pianist used the formal structure of the music as a retrieval scheme (Ericsson & Kintsch, 1995), we looked for comments about memorisation to see if they indicated use of a retrieval scheme. In response to questions from the first author about how she recalled the piece, the pianist marked, on a copy of the score, the features that she tried to consciously recall as she performed. This report provides a description of the type of retrieval cues she used.

If the formal structure of a piece of music is used as a retrieval scheme during performance, then the pianist must use the same scheme to encode the music (Baddeley, 1990, pp.180–193; Tulving & Pearlstone, 1966), and must practise using it to guide retrieval (Ericsson & Kintsch, 1995). We looked, therefore, at whether the pianist was more likely to start or stop at section and sub-section boundaries or in the middles. We also examined the total number of repetitions at each type of location. There are, of course, many reasons that a pianist might start and stop a practice segment at a particular location. She may make a mistake or be interrupted. Moreover, the pianist reported that she sometimes deliberately started in the middle of a section; by learning to start playing from many locations she was preparing for rapid recovery from a mistake during performance. However, even her formulation of this plan presupposes an organisation into sections. We therefore expected to find that the pianist started and stopped in many different locations, but that the probability of starts and stops would be higher at boundaries of the formal structure than at other locations. This would be consistent with the suggestion that the formal structure served both to encode and to retrieve the piece.

To examine the role of the formal structure in a simpler task, involving retrieval alone, the pianist was asked to write out part of the score of the Bach from memory after an interval of more than two years. The long time period was necessary in order to ensure that there would be enough errors that any effect of the formal structure could be reflected in the pattern of errors in recall. We looked

for evidence of a primacy effect. We expected that, if the formal structure was used as a retrieval scheme, then the beginning of each section and sub-section would be remembered better than the rest of the section. Primacy effects are typically obtained for free and cued recall and increase with retention interval, although the recall intervals studied in most experiments are much shorter than in our study (Fischler, Rundus, & Atkinson, 1970; Gershberg & Shimamura, 1994; Li & Lewandowsky, 1995). Long-term primacy effects (Searleman & Herrmann, 1994) of the sort that we were expecting have been obtained by Roediger and Crowder (1976) for recalling the names of presidents of the United States and when the method of loci was used as a retrieval scheme to recall ordered sequences of items (Broadbent, Cooper, & Broadbent, 1978).

METHOD

The Pianist

The pianist, Gabriela Imreh, was trained in classical piano at the Gheorghe Dima Academy of Music in Cluj-Napoca in Romania where she studied with Harald Wagner and Nina Panieva. She made her debut at age 16 with the Romanian State Philharmonic Transylvania Orchestra. She later studied with Gyorgy Sebok and is now a concert artist, performing principally in the US and Europe. During the 10-month period covered by this study she gave about 30 concerts involving two different recital programmes, and performed five concerti with orchestra, two of them for the first time. In addition, she prepared a third recital programme for recording.

The Music

We selected the third movement (*Presto*) of J.S. Bach's *Italian Concerto* from the music that the pianist planned to perform during the coming year because she expected that it would be hard to learn. The concerto was learned for the recording of an all-Bach CD (Imreh, 1996). The pianist had played Bach throughout her career, and had taught the *Italian Concerto* to a student three years before, but had never played the piece herself before the start of the present study. The *Presto* is fairly demanding because it is fast and there are no pauses or sustained notes for the pianist to "rest" on. Moreover, like most of Bach's keyboard music, it often departs from standard conceptual or motor patterns. Most bars, even half bars must be learned of themselves. The pianist judged the piece to be moderately difficult but less so than two other pieces she was preparing for the same recording.

The pianist recorded her understanding of the formal structure of the piece, after it was thoroughly learned, by marking and labelling the sections on copies of the score. The *Presto* follows the Italian rondo form described earlier, but with some modification, so that the piece consists of 16 rather than 11 major sections, as shown in Fig. 1. Most sections are divided, in turn, giving a total of 21 sub-

sections, each between 4 and 20 bars in length. The piece consists of 210 bars in total, notated in 2/4 time. The pianist's recording lasted for 3 minutes 14 seconds, a tempo requiring the production of 14.4 notes per second.

Recording Procedure

The pianist recorded her practice sessions from the first time she sat down at the piano until the recording session. The majority of the recordings were made with a video camera and tripod positioned so that the keyboard and the score were visible. Audio recordings were made of 11 sessions for which the video camera was unavailable. Data were not obtained for several sessions. The pianist's comments were largely inaudible for sessions 14–16 and the entire audio track was inaudible for sessions 18 and 19, due to an equipment malfunction. During sessions 23 and 25 the pianist played the piece twice for the listener; as these were not normal practice sessions the data were excluded. Sessions 46–50 and 52–58 were not recorded, but their approximate length was noted by the pianist. They preceded the recording of the CD. The pianist was practising the entire programme and found stopping to turn on the camera too distracting.

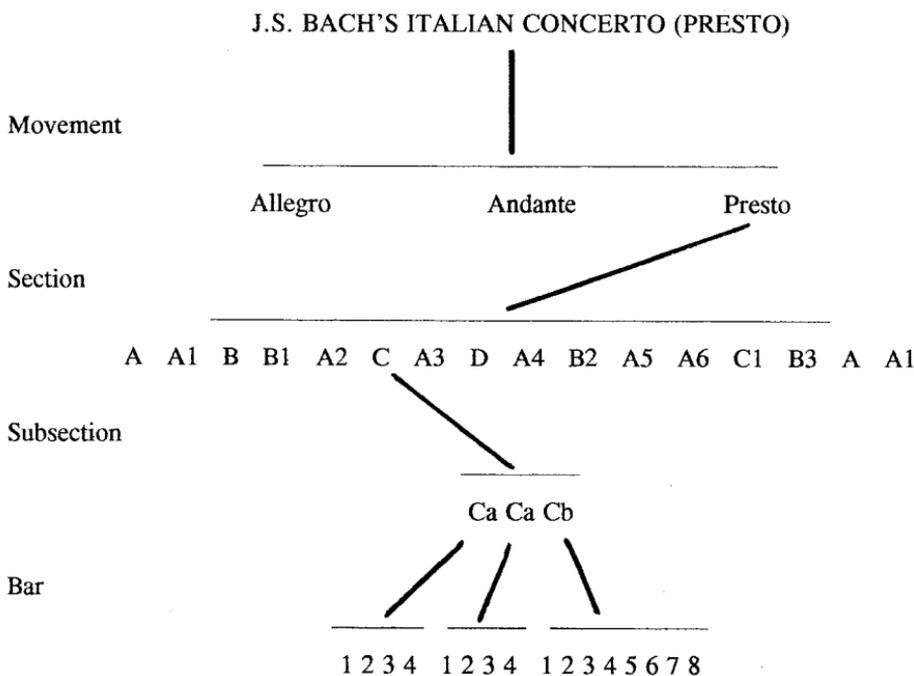


FIG. 1. The hierarchical organisation of the formal structure of J.S. Bach's *Italian Concerto (Presto)*.

The pianist was asked to describe her plans and goals at the beginning of each session and to comment on what she was doing as she practised. These verbal reports were transcribed and those relevant to the present topic are reported here.

Recall After 27 Months

Twenty-seven months after recording the *Presto*, the pianist wrote out the first page of the score from memory. During the interval, the pianist had not played the piece and had completed listening to tapes of the record sessions 24 months before the recall task. The pianist was not informed beforehand that she would be asked to recall the piece.

RESULTS

Learning and Re-learning

The pianist learned and re-learned the *Presto* three times, over a 10-month period, putting in a total of 34½ hours practice. The initial learning occurred over a three-week period and consisted of 12 practice sessions with a mean length of 57 minutes. At the end of this time she played through the piece without the score to demonstrate (to the video-recorder) that it was memorised. The second learning period occurred six weeks later, lasted for two weeks, and contained 12 practice sessions with a mean length of 41 minutes. At the end of this period, the pianist performed the piece in public with the score. The third learning period began 12 weeks later, lasted for 14 weeks, and contained 34 sessions with a mean length of 26 minutes. The learning process was completed when the pianist recorded the piece, performing without a score.

Verbal Reports of Problem Solving

Most of the pianist's comments during practice were concerned with identifying problems, proposing solutions, and evaluating playing and progress. We will describe the comments that relate to recognising familiar patterns, identifying the formal structure, and using the structure as a retrieval scheme.

Recognition of Familiar Patterns. A pianist's training includes learning fingerings for standard patterns of notes, e.g. scales, arpeggios, and diatonic triads; these are relatively automatic for a skilled player. In sessions 1–6, the most frequent topic of comment was about fingering as the pianist worked through the piece for the first time, trying out alternatives and writing decisions on the score. Many of the comments involved the identification of familiar patterns of notes. Use of a standard fingering was preferred when possible. For example, at the beginning of session 1, "I am going to change this fingering [the editors'], because it's obviously useless. I'm going to count on a straight F major fingering as opposed to what they [the editors] do ... and then I'd have to learn something brand new."

Often, decisions to use non-standard fingerings have to be made when standard patterns are interwoven in non-standard ways. This kind of unpredictability is characteristic of Bach's music and of the *Presto* in particular. In session 2 the pianist commented, "The reason I need so many [fingerings] written [into the score] is because the music is much more unpredictable ... Within one phrase you have five different things ... [with] no connection. There's ... absolutely nothing that can be used in the next bar that you've had in the bar before. So in this case, the hand has a much harder [time] picking up the patterns and storing [them] into muscle memory and, so, good fingerings [are essential]. You can't afford to confuse the hand by giving it mixed messages. You have to be consistent."

In session 6, the pianist finished working through the third movement for the first time. She then began work on the first movement, and found it much easier. Comparing the two movements at the beginning of session 7, she noted, "If you really look at the first movement though, almost everything is a pattern ... That's something the hand understands. Now babbling around like in the third movement is just very hard because it doesn't make sense. [For example], that's half of a scale ..., that's part of trill, and this is [a] rotation, and that is [an] absolutely horrible angled up mess. So, out of four bars there's nothing to rely on."

The choice of which finger to use for each note is constrained by a variety of technical, interpretive, expressive, and performance considerations. The pianist noted each type of consideration in commenting on different decisions. In session 4, for example, she mentioned a technical consideration, "See, in the fingering here there are too many turns ... So I'm eliminating them all in this one group. I hope it's going to help. [plays] It works." In session 2 she explained a choice based on interpretive considerations, "The reason he [the editor] does this [indicates a fingering] is because these are very weak fingers, so he's ... using stronger fingers so we might have more clarity." In session 4, she commented on a decision made for expressive reasons, "It's a crazy, very uncomfortable fingering, but it's going to sound better and I can get away with it if I replace ..." In session 2 she mentioned a performance consideration, "A scale usually works better if you launch it with a long predictable [sequence of] fingering." Sometimes the pianist noted conflicts between the different factors she was considering, for example in session 2, "It's really a logistic problem here. It would be ideal to keep the same fingering as much as possible, [but] the hand gets too close, so eventually on the top it must be changed. This is too close."

Decisions about fingering are crucial for a pianist and must be made at the outset. Changing a fingering produces interference. To avoid this, a pianist must anticipate how he or she will perform the music when he or she is able to play fluently and up to speed. Gabriela had to envision her interpretive and expressive goals for the piece in the initial sessions, before she could play the piece fluently. She was apparently successful. There were no comments about changes in

fingering after session 8, although it was not until the end of session 9 that she first began to play to her satisfaction, exclaiming, “It’s getting there. It’s fun to see some music finally coming out of it, because until now it’s just been pulling teeth and torture.”

Once a fingering decision is made, it must be memorised. Not surprisingly, ease of memorisation was another constraint considered in selecting fingerings. The pianist was looking for repeated patterns and, whenever possible, used the same fingering for a pattern each time it appeared. As noted earlier, she articulated this strategy in session 2, “You can’t afford to confuse the hand by giving it mixed messages. “ In session 1 she applied this principle, commenting, “And see these, these are the same pattern going up [plays], and I think it’s ... going to [help] to keep the fingering as symmetrical as possible, which helps most with my memory.” In other places the pianist created similar patterns by her choice of fingering. In session 1 she reported, “Here I change the fingerings to be perfectly symmetrical, because I know that the first finger on each beginning of a group is going to give me stability, and also [help me] memorise it.”

The pianist noted that she used some fingerings as memory cues for critical points in the music. She identified at least some of these fingerings the first time she worked through the piece. In session 1 she commented as she circled a fingering, “You need to circle the fingerings that are vital to the notes, that are vital ... just to avoid mis[takes].” And a minute later, “The reason I circled the D is because that’s where ... the theme splits up.”

Identification of the Formal Structure. The formal structure of a piece is determined by the sequence of similar and dissimilar thematic material. The Italian Rondo structure of the *Presto* was broadly familiar to the pianist before she began work on the piece, because she had taught it three years earlier. However, the detailed identification of the complex thematic structure of the piece was the subject of commentary until session 17, when she first practised playing without a score.

The pianist made her first comments about the structure in session 2, noting, “What I am going to do is to check if my previous fingering is going to fit perfectly this sequence, this repetition in another key” and, “[This is] probably another repeat of the main theme, so ... At the end of this session, she looked over the remaining pages of the score, comparing the various returns of the A and B themes she had been practising. “The last page is pretty much a repeat of the first, at least some of it is ... Tiny changes sometimes are the worst ... Oh, this is not going to be hard. Again we have a pattern and it’s not hard. [plays], [I] recognise the problem. So, a lot of the third page is going to be fairly easy ... The last two pages are very much repeated material, ... transposed in different keys.” In session 4 she commented more frequently on the structure as she worked to learn the difference between repetitions of the same theme. “That’s the turning

point” and later “At the seams [between sections] I should probably practise more ... I’m confusing [it] with a similar place ...”

As this last comment indicates, similar passages can save memory work, but are also a potential source of interference. In the first session, the pianist commented on the difficulty of distinguishing the A theme at the beginning and end of the piece, “The left hand is a problem too, because it changed the pattern after [plays]. Instead of going to the top G, it goes to the left bottom G.” In session 4, she made the same comparison again, “And here it’s basically the same theme but ... the bottom G steps down, and, um, it’s a very subtle change.” In session 6, she noted, “I have to rework pretty carefully this section. It’s never been solid, but now I have to put the two versions [of the same theme] together ...” In session 12 she commented, “I am confusing this bar with the one that is [an] almost identical start for left hand ...” and at the end of the session noted, “Probably now the seams [between sections] are quite obvious ... I have to now check each transition, because every time it’s something different.”

The identification of different repetitions of the same theme became critical in session 17, when the pianist began to work on playing without the score. She spent the first half hour of the session comparing the differences between the various repetitions of the A and B themes. She began by comparing the A themes at the beginning and end of the piece, “It’s bar ... 8,9, around there, and number two [bars 194–5]. The difference is really minor, but it has to be drilled in [plays]. Here [plays], all the difference is in the left hand ... Okay, [let’s] see if we can come in from an earlier place [plays].” Then, “I’ll try [both passages] again, [plays]. Uh, I made a mistake. I really want to play the first one and that’s the irregular one.” After ten minutes, she moved on to the B theme. “And actually there’s another conflict here, on bar ... 25. [plays] That’s one, and the other [bar 167] is in the same key, but both turns are different. The left hand turns down in the middle and the ending is different ... I should probably practise ...”

The pianist then put the two themes together, “I think I am going to work on these larger sections. There are definitely a lot of conflicts going on between the first two pages and then the last page and a half ...” Five minutes later, referring to the A theme, “Oh, it still is driving me crazy. There’s another one that’s different here. I have no idea how it goes. I’m all confused.” After a couple of minutes’ work the pianist summarised her conclusions about the various repetitions of the A theme, “Okay, so ... this is our second ending, third ending actually. One was [plays]. Oh, sorry [plays]. The second one is right at the end [of the segment] that I practised [plays]. And this is the third, a different key.” After another five minutes’ work the pianist was ready to begin practising without the score, “I’ll try to play the first page. Let’s see, how can I do this? I’ll play the first ... two [pages] by memory ... and keep the last page for memory again.” The pianist then played through the whole piece several times with just the middle four pages of the score open in front of her. Finally, she closed the score and played the entire piece from memory four more times.

Use of the Formal Structure as a Retrieval Scheme. As the preceding quotations make clear, subtly different repetitions of the A and B themes were an important source of interference for the pianist. As Gabriela had noted in session 2, “Tiny changes sometimes are the worst ...” For example, the difference between the A theme at the beginning and end of the *Presto* is very slight, but confusing the two could put the pianist at the end of the piece almost before she had begun. In order to avoid this kind of mistake, she monitored where she was in the piece, particularly as she made the transition into the critical sections. The pianist referred to transitions of this sort as “switches”.

In an interview conducted after the piece had been recorded, Gabriela described the problem these switches presented, “One variant puts you on the track for the second return of the A theme. A slightly different variation puts you at the end of the piece before you know what has happened. You are like a train coming up to a switch. If you set the switch one way, you go in one direction; if you set it the other way, you go in the other direction. You have to throw the switch before you get there, or you are liable to have a train wreck.” The pianist used the same metaphor at the end of session 12, “Well, that’s not awful, but, I feel like the memory process is just pretty much 60% done, and there’s a lot of work to be done. Mostly being able to switch to a different section is like being a train engineer, where you have to switch tracks; and that’s basically what I have to do. Otherwise you end up in all kinds of places.”

In order to monitor transitions between sections consciously, the pianist needed to retrieve a conceptual representation of the next section from memory as she played. In session 5, the pianist anticipated that the speed of retrieval required for performance tempo would present a problem. “Now for me to actually [play it at a] tremendous speed level, I think one of the biggest problems for performance is going to be that, literally for seven pages, ... probably about five minutes, there’s absolutely no place to relax ... it is pure concentration. You can tell from my horrible practising, that as soon as my concentration goes ... I’m making an enormous amount of mistakes. And, of course, many subtle [differences] are going to surface, like two fingerings that interfere with each other. [These differences are] just going to mean that I will really have to concentrate on this switch every time I play either one of them.”

At the end of session 17, after working for the first time on playing without the score, Gabriela described the retrieval cues that she was practising to establish. “Eventually, at this level, you start to have a sort of a map of the piece in your mind. And you start to sort of focus on certain places in it. I’ll try to tell you [what they are]. There are a couple of key places, like bar 7 ... I was really concentrating on the left hand to make the [correct] switch. Bar 23, the left hand again. Bar 32, right hand mostly. I have a thing in bar 42 where I have to remember to go all the way to the G, but I can get through it ...” She continued in this way, identifying critical memory cues, through to the end.

In session 31 the pianist decided to increase the tempo by nearly one third. She did this in session 32 and continued to work on this goal through session 43. In session 35, she noted, "I'm still cracking up here and there, but it's getting better. The intensity of concentration that's required is amazing. If you miss any beat, you're gone." In one of the later interviews, Gabriela observed about her practice during this time, "A lot of my later practice of the *Italian Concerto* was practising throwing those switches. 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."

Between sessions 31 and 32 the pianist constructed a visual representation of the specific memory cues she rehearsed as she played. An example is shown in Fig. 2. The places in the music labelled by the arrows indicate features that the pianist was deliberately trying to think of as she played. Three types of feature are represented by arrows of different lengths. *Basic* features include fingering (e.g. the fingerings that the pianist had circled in the early sessions), technical difficulties, and groups of notes that form identifiable conceptual "chunks". *Interpretive* features include phrasing, dynamics, tempo, and pedalling. *Expressive* features are places where the pianist tried to elicit changes in expression or mood, e.g. "Light but mysterious", "Surprise", "Hold back". The features marked thus represent the conceptual cues that the pianist retrieved from memory as she approached each location in the music. These cues, in turn, would elicit the motor sequences that produced the notes.

In explaining the representation in Fig. 2, the pianist reported that, in the later practice sessions, her goal was to get the features shown in the figure to come to mind rapidly and reliably enough to guide her performance. Her comment from session 35, reported earlier about the need for concentration reflected the fact that she was not yet comfortable with her automaticity in recalling the performance cues. In her account of the memory cues in Fig. 2, Gabriela stated the intention that, by the time she was ready to perform, she would be able to give most of her attention to the expressive cues because the other performance cues would come to mind automatically. She appeared to be close to this goal in session 41 when she announced, "There isn't that much more that I can do ... I still have to lighten up the touch to the maximum, but I have to make sure that the piano responds."

Starts and Stops

Practice segments were more likely to start and stop at boundaries of the formal structure than at other locations. This is illustrated in Fig. 3 which is taken from session 3. Practice is represented as a cumulative record with the score on the horizontal axis and cumulative number of repetitions on the vertical axis. Each line represents the playing of one practice segment, i.e. a sequence of notes

Performance Cues

Expressive
Light but mysterious

Interpretive

Basic

Surprise

Hold back

Surprise

Expressive

Interpretive

Basic

Start building cresc.

No holding back

Prepare ↓

forte

forte

FIG. 2. Expressive, interpretive, and basic musical features attended to during performance, for section C of J.S. Bach's *Italian Concerto* (*Presto*) (C = conceptual, D = dynamic, F = fingering).

played without stopping. Each time the pianist stopped, the record begins again on the next line up.

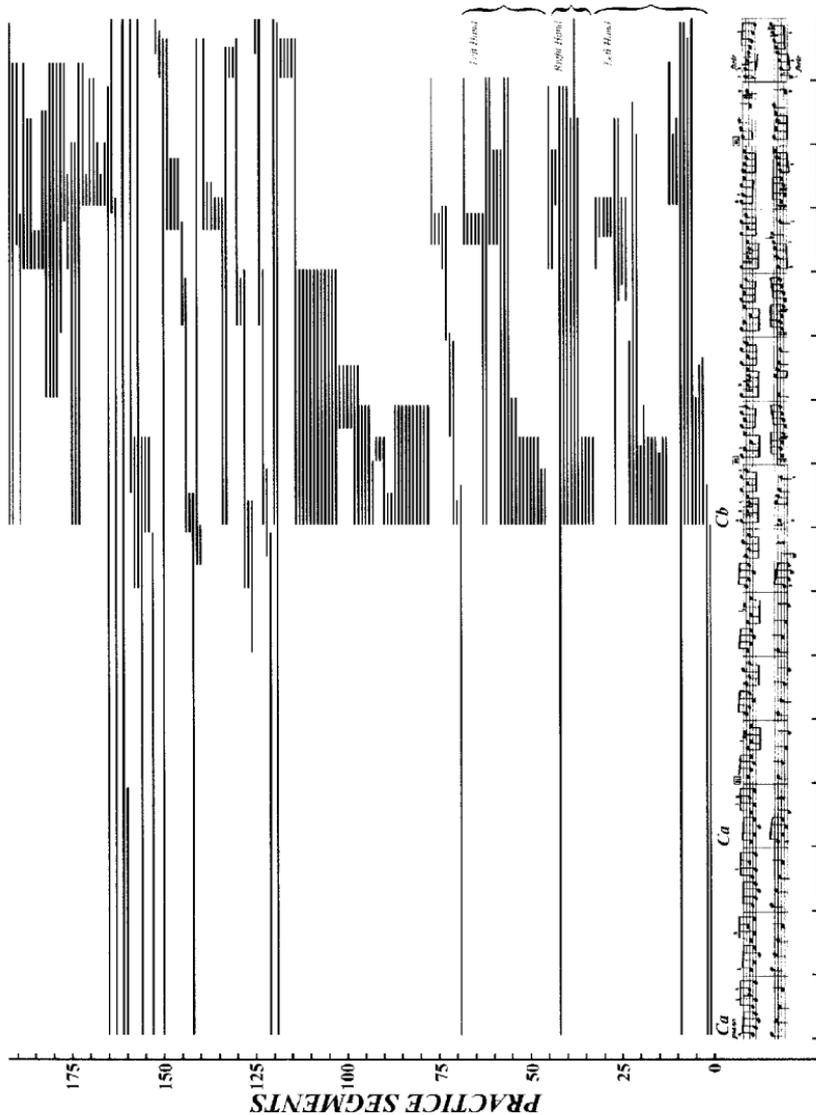
We compared the number of practice segments that started and stopped at segment boundaries with the number that started and stopped in other locations. We counted the number of *starts*, *stops*, and the *total* number of repetitions of each bar. The independent variable for the study was provided by classifying bars according to their position in the formal structure, as at the beginning or end of a section or sub-section or in the middles. Sessions were combined into seven stages of practice by summing across sessions and dividing by the number of sessions. Sessions in each of the first two learning periods were divided into two stages (sessions 1–6, 7–12, 13–17, 20–24) and those in the third learning period into three stages (sessions 26–32, 33–39, 40–45, and 50–51).

The results were evaluated by analyses of variance in which bars served as the random variable and the independent variables were location in the formal structure (between groups) and stage of practice (repeated measures). The first and last bars were omitted from the data because any account of practice would predict segments would start at the beginning and stop at the end of the piece. All effects reported were statistically significant, $P < .05$, unless otherwise noted.

Table 1 shows the mean number of starts and stops per bar, as a function of its location in the formal structure. Starts and stops were more likely to occur at boundaries in the formal structure than in the middles of sections and sub-sections. Starts were more likely to occur at the beginnings of sections and sub-sections. For starts, the effects of location in the formal structure, stage of practice, and their interaction were significant, $F(4,203) = 16.60$, $MS_e = 3.31$, $F(6,1218) = 53.89$, $MS_e = 1.46$, and $F(24,1218) = 4.55$, $MS_e = 1.46$ respectively. Separate analyses for each stage of practice, followed by Bonferroni comparisons, showed that beginnings of sections differed from middles at each stage of practice except for sessions 40–51 and the beginnings of sub-sections differed from middles at each stage except for sessions 20–24 and 40–51.

Practice runs were more likely to stop at the end of a section or sub-section or at the beginning of the following section. For stops, the effect of location, stage of practice, and their interaction were significant, $F(4,203) = 3.89$, $MS_e = 2.03$, $F(6,1218) = 57.38$, $MS_e = 1.09$, and $F(24,1230) = 2.53$, $MS_e = 1.09$, respectively. Separate analyses for each stage of practice, followed by Bonferroni comparisons, showed that, compared to the middles, there were more stops at the beginnings of sections in sessions 1–6, more stops at the beginnings and at the ends of sections in sessions 13–17, and more stops at the ends of sub-sections in sessions 26–32 and 33–39.

We also asked whether the pianist's practice was further organised by the expressive phrases into which the sub-sections of the piece could be divided. The expressive cues that the pianist reported were treated as the beginnings of phrases. There was no effect for beginnings and ends of expressive phrases; the number of starts and stops at phrase boundaries did not differ from middles.



BARS

FIG. 3. Practice of section C of J.S. Bach's *Italian Concerto (Presto)* during session 3, represented as a cumulative record.

TABLE 1
Starts and Stops

Stage of Practice Sessions	Starts			Stops							
	Begin Major	Begin Minor	End Major	Location in Formal Structure			Begin Major	Begin Minor	End Major	End Minor	End Middle
				End Minor	Middle						
1-16	3.5	4.0	2.3	1.6	1.1	2.7	2.9	2.2	1.7	1.5	
7-12	1.4	2.6	1.2	0.9	1.4	1.5	1.5	0.5	1.4	0.7	
13-17	1.1	1.6	0.5	0.6	0.3	1.1	0.4	1.1	0.5	0.3	
20-24	0.4	0.5	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.1	
26-32	1.3	1.0	0.3	0.2	0.2	0.4	0.4	0.6	1.0	0.2	
33-39	0.5	0.6	0.1	0.1	0.1	0.2	0.2	0.1	0.5	0.2	
40-51	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	
N	10	62	10	62	72	10	62	10	62	72	

Mean number of starts and stops, as a function of location in the formal structure and stage of practice.

The total number of repetitions of each bar was also examined. There were no effects of location in the formal structure, $F_s < 1.0$.

Recall after 27 Months

Initially, the pianist was asked to play the piece from memory, but she was unwilling to do this because she felt that the mistakes she would make would interfere with her later re-learning of the piece. Instead, she offered to write out part of the score from memory. The pianist started at the beginning and continued for about 15 minutes, until the task became too onerous, by which time she had completed the first page of the score, consisting of 32 bars, containing six subsections of the piece. At this point, the pianist took her manuscript version of the score to the piano and played it. This allowed her to recall some additional notes, and to correct some of the notes that she had already recalled. She added these to her manuscript version of the score using a different-coloured ink.

Recall was fairly accurate. A simple comparison with the score was sufficient to distinguish notes whose pitch had been correctly recalled from those incorrectly recalled or omitted. Notes were scored as correct if they were on the correct stave line. Duration was not considered in scoring. Notes scored for left and right hand were counted separately. The probability of correct recall for each bar was computed by dividing the number of notes correctly recalled for each bar by the total number of notes possible. Initial recall was 79% correct for the right hand and 52% correct for the left hand. When the recalled score was played at the piano an additional 2% of notes were recalled for the right hand and 9% for the left hand.

Table 2 shows the mean probability of recalling the notes in each bar when the music was initially written down, and when the recalled score was played at the piano. Probabilities are shown separately for right and left hands, and separately for bars at the beginning of each section and sub-section (*beginning*) and for bars that appeared later in the section or sub-section (*later*). The first 32 bars include the first six sub-sections of the piece so there were 6 beginning and 26 later bars. Inspection of Table 2 indicates that initial recall was better for the right hand than for left hand, and better for the beginning bars of each section than for later bars. These differences were evaluated by an analysis of variance in which bars ($N = 30$) was the random factor, hands (right or left) a repeated-measures factor, and location in the formal structure (beginning or later) a between-groups factor. The effects of hands and location in the formal structure were both significant, $F(1,30) = 5.53$, $MSe = .07$, and $F(1,30) = 7.03$, $MSe = .21$ respectively. There were no significant effects for recall at the piano.

DISCUSSION

Concert pianists make their living performing in public from memory. They provide an interesting test of the principles of expert memory because, unlike other types of memorist, they are able to rely heavily on motor memory. Our study suggests that pianists use conceptual or propositional memory in ways that are very similar to other expert memorists (Chase & Ericsson, 1982; Ericsson & Kintsch, 1995; Ericsson & Oliver, 1989). The pianist we studied first developed a detailed conceptual representation organised by the formal structure, and then worked to increase the speed with which she could use the organisation to retrieve critical features in later sessions. The conceptual representation played four important roles during performance. It provided the cues that elicited the motor performance. It allowed the pianist to keep track of where she was so that she did not, for example, bring the piece to a premature close by playing the last return of a theme in place of an earlier one. It helped her to give an expressive

TABLE 2
Recall After 27 Months

<i>Location in Formal Structure</i>	<i>Right Hand</i>		<i>Left Hand</i>	
	<i>Beginning</i>	<i>Later</i>	<i>Beginning</i>	<i>Later</i>
N	6	26	6	26
Initial Recall	1.00	0.75	0.94	0.42
Recall at Piano	0.00	0.03	0.00	0.12

Mean probability of initial recall and recall at the piano of notes scored for right and left hands as a function of location in the formal structure.

performance by allowing her to think about the emotions she wanted to convey. And, it provided a way to continue the performance in the event of a disruption; the pianist could jump forward to a new starting point and continue to play.

In order to use the conceptual representation in these ways, the pianist had to know exactly where she was as the performance unfolded. Because the *Presto* was fast, the coordination of the mental representation with the activity of the hands was not a trivial problem. Retrieval of successive cues was initially slower for the conceptual than for the motor representation. The pianist needed extensive practice to bring the operation of her conceptual retrieval scheme up to the speed at which she wanted to play, and at which her hands were able to play.

These conclusions are based on a single artist. Although they need to be confirmed by observation of other pianists, there is reason to expect that our results concerning the use of the formal structure will be replicable. They confirm Miklaszewski's (1989) informal description of the practice of an expert pianist as dividing the music into sections on the basis of its formal structure, and support the pedagogical recommendation to use the formal structure to organise practice and aid memory (e.g. Lehrer, 1988; Sandor, 1981; Shockley, 1986).

Verbal Reports of Problem Solving

Gabriela's reports of her problem solving during practice described how she used familiar patterns as a basis for fingering decisions, identified the formal structure of the *Presto*, and practised using it as a retrieval schema (Ericsson & Kintsch, 1995). Memorising the formal structure was a central part of memorising the piece. This was reflected in the juxtaposition of comments about the formal structure with comments about memorisation. In session 17, when the pianist first practised playing without the score, she devoted the first half hour of the session to a detailed review of the differences between the various repetitions of the A and B themes. Only when this review was completed did she begin to practise playing without the score for the first time. Further evidence of the use of the formal structure as a retrieval scheme came from the pianist's account of her efforts to increase the speed and automaticity with which she was able to retrieve conceptual memory cues in the later practice sessions.

Although the formal structure provided the hierarchical organisation of the piece that allowed the pianist to know where she was, a more detailed level of representation was needed for the particular music in each section (Imreh & Chaffin, 1996/97). Gabriela gave a detailed report of the specific memory cues she used. These lower-level cues were what she tried to bring to mind as she played. They included the critical fingerings that she had circled in the initial practice sessions, decisions about interpretation, such as dynamic changes, and her expressive goals, the emotions that she was hoping to convey to her audience such as "mysterious" and "surprise". Beyond this level of detail, the pianist did not normally think about the particular phrases and notes that she played, but relied on her hands to produce the appropriate notes automatically.

The pianist's verbal reports also provide a detailed picture of how she made use of familiar patterns in making fingering decisions (Ericsson & Kintsch, 1995). When possible she used standard fingerings for familiar patterns of notes to reduce memorisation. Non-standard fingerings were used only when other considerations imposed conflicting demands. These decisions were based on the satisfaction of multiple constraints including technical, interpretive, expressive, performance, and memory requirements. The evaluation of these different considerations was accomplished, in part, through the use of heuristic rules, some quite specific, e.g. "Launch scales with a long sequence of fingers", others more general, e.g. "Avoid interference".

The fingering decisions the pianist made in sessions 1–6 anticipated interpretive and expressive effects that would become the focus of practice in later sessions. Gabriela mentioned interpretive and performance issues as early as session 2. It was not until later, however, that she was able to realise her interpretive goals in these areas in performance. The conclusion that the pianist's fingering decisions anticipated future needs is reminiscent of chess experts' ability to anticipate future moves while rapidly selecting moves on the basis of familiar configurations (Gobet & Simon, 1996a). In the present case, familiarity with musical theory, compositional conventions, and performance technique allowed the pianist to see beyond the immediate problem of fingering to the interpretive and performance goals she would work on in later practice sessions. She was able to make decisions about fingering in the initial practice sessions that served her ultimate, expressive goals, even though these goals could not be fully realised immediately.

Starts and Stops

Practice was organised by the formal structure of the music. Practice segments were more likely to start at boundaries of this structure at every stage of practice except for the last, and were more likely to stop at boundaries in four of the seven stages of practice. This is not to say that the majority of practice segments started and stopped on section boundaries. There were only 74 bars at the beginnings and ends of sections and sub-sections, whereas there were 136 bars in the middles. But, given that a practice segment could start or stop anywhere in the piece, it was more likely to start or stop at a structural boundary than at other locations. The absence of a similar effect for boundaries between phrases strengthens the conclusion that it was the formal structure of the piece rather than some other organisation that determined where the pianist started and stopped.

The effects of structural boundaries provide behavioural support for the pianist's verbal report that she identified the formal structure and used it to guide her retrieval. Every practice segment provides an opportunity for encoding. Segments played without looking at the score also require retrieval from memory. The effect of the formal structure on practice thus indicates that it was used for both encoding and retrieval.

Our use of practice data to draw conclusions about retrieval is unusual. Retrieval processes are normally studied after memorisation is completed, using measures such as error rate and response time. This approach was not possible in the present case because concert pianists make few errors in performance and the timing of their responses is closely controlled for expressive purposes (Shaffer, 1981, 1984; Sloboda, 1983). Practice, on the other hand, provided a readily available alternative source of information about memorisation, one in which encoding and retrieval occurred together.

Recall

Verbatim recall of 79% and 52% after 27 months is surprisingly good by everyday standards (Neisser, 1982, pp.93–237). High levels of recall over extended periods are, however, characteristic of the recall of experts when the material is relevant to their field of expertise (e.g. Gobet & Simon, 1996b). The recall data also indicate that, as with other types of expert memory, the pianist used an hierarchical retrieval scheme which, in this case, was based on the formal structure of the music. This was suggested by the finding that the first bar in each section or sub-section was recalled better than later bars.

This long-term primacy effect is similar to effects reported by other investigators who have observed the use of retrieval schemes designed to preserve information about order (Broadbent et al., 1978; Roediger & Crowder, 1976). There is disagreement about the explanation for primacy effects. One early theory, that the effect is due to the opportunity to rehearse the early items in a list more than later ones (Fischler et al., 1970; Rundus, 1971), is inconsistent with our finding that beginnings and ends did not receive a higher total number of repetitions than middles. An alternative explanation for the primacy effect, which is more compatible with the present results, is that items at the beginning of a list were more salient than later items (Murdock, 1960; Neath, 1993; Neath & Knodler, 1994). Salience may also account for the fact that the right hand part was recalled better than the left.

The recall task provides an important complement to the practice data, because it is a measure of retrieval alone, rather than reflecting both retrieval and encoding processes, as was the case for practice. The recall task also has the advantage of being similar to the tasks that memory researchers have conventionally used to study memory processes.

Conclusion

Our results provide the first evidence that the principles of expert memory apply to concert soloists (Chase & Ericsson, 1982b; Ericsson & Oliver, 1989). Experts are often capable of feats of memory that appear to be outside the normal range because extended practice of a retrieval scheme has developed the ability to

recover information from long-term memory rapidly and reliably (Chase & Ericsson, 1982a; Ericsson & Kintsch, 1995). The retrieval scheme in this case was provided by the formal structure of the music. In the early practice sessions the pianist worked on the problem of identifying and memorising the way the Italian Rondo form was implemented. In later practice sessions, she was concerned with the problem of increasing the speed and reliability with which she could use her conceptual representation to cue the automatic actions of her hands.

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