Research Article

PRACTICING PERFECTION: Piano Performance as Expert Memory

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Abstract—*A concert pianist recorded her practice as she learned the third movement,* Presto*, of J.S. Bach's* Italian Concerto*. She also described the formal structure of the piece and reported her decisions about basic features (e.g., fingering), interpretive features (e.g., phrasing), and cues to attend to during performance (performance cues). These descriptions were used to identify which locations, features, and cues she practiced most, which caused hesitations when she first played from memory, and which affected her recall 2 years later. Effects of the formal structure and performance cues on all three activities indicated that the pianist used the formal structure as a retrieval scheme and performance cues as retrieval cues. Like expert memorists in other domains, she engaged in extended retrieval practice, going to great lengths to ensure that retrieval was as rapid and automatic from conceptual (declarative) memory as from motor and auditory memory.*

A hallmark of expertise is the ability to memorize material relevant to the field of expertise with an efficiency that seems superhuman (Chase & Simon, 1973). Expert musicians are no exception; their biographies are full of tales of amazing feats of memory (e.g., Cooke, 1913/1999, p. 41). The abilities of other expert memorists have been attributed to the use of highly practiced retrieval strategies (Ericsson & Kintsch, 1995). It is not obvious, however, that principles of expert memory derived from the study of memory for chessboards (Chase & Ericsson, 1982; Chase & Simon, 1973), digit strings (Chase & Ericsson, 1982; Thompson, Cowan, & Frieman, 1993), and dinner orders (Ericsson & Oliver, 1989) apply to musical performance. Motor and auditory memory play a crucial role in musical memory but not in these other domains. Do the same principles apply?

To find out, we observed the practice of a concert pianist (the second author) as she learned a new piece for performance. The pianist's intuition was that, despite the clear primacy of motor and auditory memory, conceptual (declarative) memory is vital in her own preparation for performance. Although pianists can rely primarily on motor and auditory memory (Aiello, 2000), experienced performers usually avoid doing so. When things go wrong during a performance, as they inevitably do, the pianist must know where he or she is in the piece, and be prepared to put the performance back on track. This requires use of conceptual memory to restart the motor sequence. With good preparation and a little luck, the audience will never notice.

The feats of expert memorists have been explained in terms of three principles: meaningful encoding of novel material, use of a well-learned retrieval structure, and rapid retrieval from long-term memory (Ericsson & Kintsch, 1995). All three appear to apply to expert piano performance. According to the first principle, experts' knowledge of their domain of expertise allows them to encode new information in terms of ready-made chunks already stored in memory (Mandler & Pearlstone, 1966; Miller, 1956; Tulving, 1962). For a pianist, these include familiar patterns like chords, scales, and arpeggios, whose practice forms an important part of every pianist's training (Halpern & Bower, 1982).

According to the second principle, expert memory requires a retrieval scheme to organize the cues that provide access to the chunks of information in long-term memory (Ericsson & Oliver, 1989). For a pianist, the formal structure of the music provides a ready-made hierarchical organization that could conveniently serve as a retrieval scheme (Chaffin & Imreh, 1997; Williamon & Valentine, 2002). For example, the piece we studied, the *Italian Concerto* (*Presto*) by J.S. Bach, is divided into movements, sections, subsections, and bars as shown in Figure 1. (The additional levels shown in the figure are discussed later.)

According to the third principle, prolonged practice can dramatically increase the speed of retrieval from conceptual memory to the point where an expert can rely on long-term memory to perform tasks for which most people would rely on working memory (Ericsson & Kintsch, 1995). Rapid memory retrieval is also important in piano performance; it is easy to let the hands "run away," as motor performance outstrips activation of the conceptual representation. Practice is needed to coordinate retrieval from conceptual long-term memory with the motor performance.

One reason for choosing the *Presto* for this study was that its fast tempo provides little opportunity for the performer to think ahead, making rapid, automatic retrieval from conceptual long-term memory essential. The pianist reported that integrating her thinking with the rapid actions of her hands required practice of *performance cues*, features of the music attended to during performance. During practice, a pianist makes many decisions about basic issues (e.g., fingering) and interpretation (e.g., phrasing) whose implementation becomes automatic with practice. But a few problem spots continue to require attention during performance (e.g., a tricky fingering or critical phrasing). The pianist reported that she practices thinking of these places during performance so that they come to mind automatically, along with their associated motor responses. These are the *basic* and *interpretive* performance cues.

During practice, attention is directed mainly toward problems. In performance, however, problems must recede into the background so that musical expressiveness can take center stage, both in the mind of the performer and (as a result) in the aesthetic experience of the audience. This transformation does not happen by magic but requires preparation. The pianist reported that, in the final weeks before a performance, she practices attending to *expressive performance cues*, which represent the feelings she wants to convey to the audience (e.g., surprise, gaiety, excitement). Expressive goals are identified earlier, but in this final phase of practice their use as retrieval cues is deliberately rehearsed.

To test these intuitions, the pianist identified the performance cues she used for the *Presto*, along with the basic and interpretive decisions made during practice, and critical points in the formal structure. Practice was examined to see whether these places were repeated more, or used more often as starting or stopping places. We also looked at occasions when the pianist first played from memory (*memory runs*), to see if hesitations occurred at these points. Finally, 2 years later, the pi-

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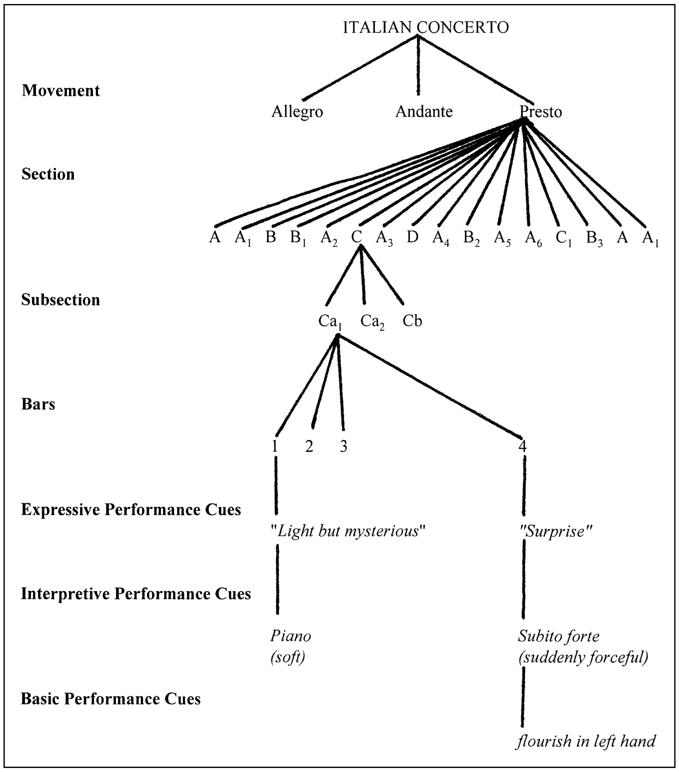

Fig. 1. The formal structure of the *Presto*. Main themes (sections) are represented by capital letters. Section C is "unpacked" into subsections (Ca_1, Ca_2, and Cb), and subsection Ca_1 is further unpacked into its performance cues.

anist wrote out the score from memory, and we looked at whether section beginnings and bars containing memory cues were recalled better than other bars. Such effects would confirm the pianist's description of her preparation for performance, suggesting that the formal structure provided a retrieval scheme and that performance cues were used for memory retrieval.

METHOD

The Pianist

Gabriela Imreh was trained in classical piano in Romania and now lives in the United States, performing as a concert pianist. During the 10-month period covered by this study, she gave about 30 concerts involving two recital programs, performed five concerti with orchestra, and prepared a new recital program that included the *Italian Concerto*.

The Music

The *Presto* of Bach's *Italian Concerto* was learned for the professional recording of an all-Bach CD (Imreh, 1996).[1] The pianist had played Bach throughout her career, and had taught the *Italian Concerto* to a student, but had never played the piece herself before the start of the study. The *Presto* is of moderate difficulty (Hinson, 1987), is scored in 210 bars in 37 sections (including subsections), is notated in 2/4 time, and lasts for 3 to 4 min.

Procedure

Practice

The pianist videotaped her practice from the first time she sat down at the piano until the piece was ready to record. During practice, she commented periodically on what she was doing. We report data for 28.5 hr of practice in 42 sessions out of a total of 33.5 hr and 57 sessions. The final 12 sessions were not recorded because learning had been completed and the piece was simply being maintained in readiness. Two sessions were excluded because the recording equipment malfunctioned, and 1 was excluded because it took place during a discussion of the research. For each of the sessions studied, the bar on which each practice segment started and stopped was recorded, and the number of starts, stops, and repetitions of each bar was counted (see Chaffin & Imreh, 2001). Reliability was above $r = .9$ for starts and repetitions and above .8 for stops.

Memory runs

The first few times the pianist played through the piece from memory were punctuated by hesitations and pauses. These memory runs, in Sessions 8 (Run 8.1) and 12 (Runs 12.1 and 12.2), were examined to see where hesitations occurred. Interbar intervals (IBIs) were measured, with a commercial sound-wave-processing program, from the start of one bar to the start of the next. When a passage was repeated, the first complete playing of each bar was measured. To assess the contribution of deliberate variations in expressive timing, we also measured IBIs for the performance recorded on the CD.

Recall after 2 years

Twenty-seven months after the piece had been recorded, the pianist was unexpectedly asked to write out the first page of the score (32 bars in six sections) from memory, and the probability of correctly recalling the notes in each bar was computed (see Chaffin & Imreh, 1997, for details).

Pianist's reports

A pianist's decisions during practice can be described using 10 dimensions (Chaffin & Imreh, 1997; see Table 1). Three *basic* dimensions require attention just to produce the notes (familiar patterns, fingering, and technical difficulties), and four *interpretive* dimensions shape the musical character of the piece (phrasing, dynamics, tempo, and pedaling). Three *performance* dimensions describe the cues attended to during performance (basic, interpretive, and expressive). In addition, knowledge of the formal structure allows identification of *boundaries* between sections and of *switches*, places where one repetition of a theme diverges from another very similar passage. The pianist was asked to record the sections and switches on a copy of the score after Session 12. Features on each of the 10 dimensions were similarly recorded approximately 3 months after the final performance (see Fig. 2; Chaffin & Imreh, 2001).

1. The performance of the *Presto* whose learning is described here can be downloaded from the Web page of the first author, accessible at http://psych.uconn.edu by clicking successively on <go to main site>, <faculty>, and <Roger Chaffin>.

Table 1. *Dimensions that require attention while learning a new piece of music for performance*

Basic	
	Fingering—nonstandard choices about which fingers to use to play particular notes
	Technical difficulties—places requiring attention to motor skills (e.g., jumps)
	Familiar patterns of notes—e.g., scales, arpeggios, chords, rhythms
Interpretive	
	Phrasing—grouping of notes to form musical units
	Dynamics—changes of loudness, or emphasis of a series of notes in order to form a phrase
	Tempo—variations in speed
	Pedal—used mainly to form phrases by giving a series of notes the same coloring
Performance	
	Basic cues—familiar patterns, fingering, and technical difficulties still requiring attention in performance
	Interpretive cues—phrasing, dynamics, tempo, and use of pedal still requiring attention in performance
	Expressive cues—emotion to be conveyed during performance, e.g., surprise, excitement
Musical structure	
	Section boundaries—beginnings and ends of musical themes, dividing the piece into sections and subsections
	Switches—places where two (or more) repetitions of the same theme begin to diverge

Analysis

To determine whether the performance dimensions and formal structure affected practice and recall, we used regression analyses to relate the number of features reported for each bar to how much the bar was practiced, how readily it was played from memory, and how accurately it was recalled. Dependent variables were the number of starts, stops, and repetitions of each bar in practice, log-IBI during memory runs, and probability of correct recall. Predictor variables were the number of features per bar for each of the 10 dimensions, number of notes per bar, and four measures reflecting location in the formal structure: first or last bar in the section, serial position numbered from the beginning of the section, and number of switches. All predictor variables were entered simultaneously. Because of the small number of bars in the recall task, predictor variables were limited to three measures of location in the formal structure and the three performance dimensions.

RESULTS AND DISCUSSION

Practice

Preparation of the *Presto* took place in three learning periods spread over 10 months. The first period consisted of 11 1/2 hr of practice in 12 sessions over 4 weeks. After a break of 15 weeks, the second period consisted of 8 hr of practice in 12 sessions over 2 weeks, at the end of which the pianist performed the piece in recital. After another break (of 9 weeks), the third learning period consisted of 14 hr of practice in 33 sessions over 11 weeks; the last 12 sessions were devoted to maintenance practice and not recorded.

The pianist clearly engaged in extended practice, but how much of this was devoted to memory retrieval? The answer is provided by the regression analyses of the number of times that each bar was repeated or used as a starting or stopping place in each learning period, shown in Table 2.

Musical structure

Bars containing critical points in the formal structure were practiced more than other bars. In all three learning periods, practice segments started and stopped more at section boundaries than at other locations (Chaffin & Imreh, 1997; see also Miklaszewski, 1989, 1995, and Williamon & Valentine, 2002). The effect of serial position on repetitions in Periods 2 and 3 suggests that this use of the formal structure to organize practice was reflected in memory. Bars later in a section were repeated more than earlier bars, suggesting that they were harder to remember. This is the standard effect of serial order on memory and suggests that the pianist's memory for the piece was organized by sections (Broadbent, Cooper, & Broadbent, 1978; Roediger & Crowder, 1976).

Playing was interrupted at switches as the pianist remembered which path to take. As the pianist put it in an interview shortly after the CD performance,

> A lot of my later practice . . . was practicing 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.

Because the approach to a switch does not provide cues about which way to continue at the switch, the right choice cannot be made automatically. A conceptual representation of the formal structure had to be retrieved from long-term memory. When retrieval did not occur quickly enough, playing stopped. Stops were more frequent at switches

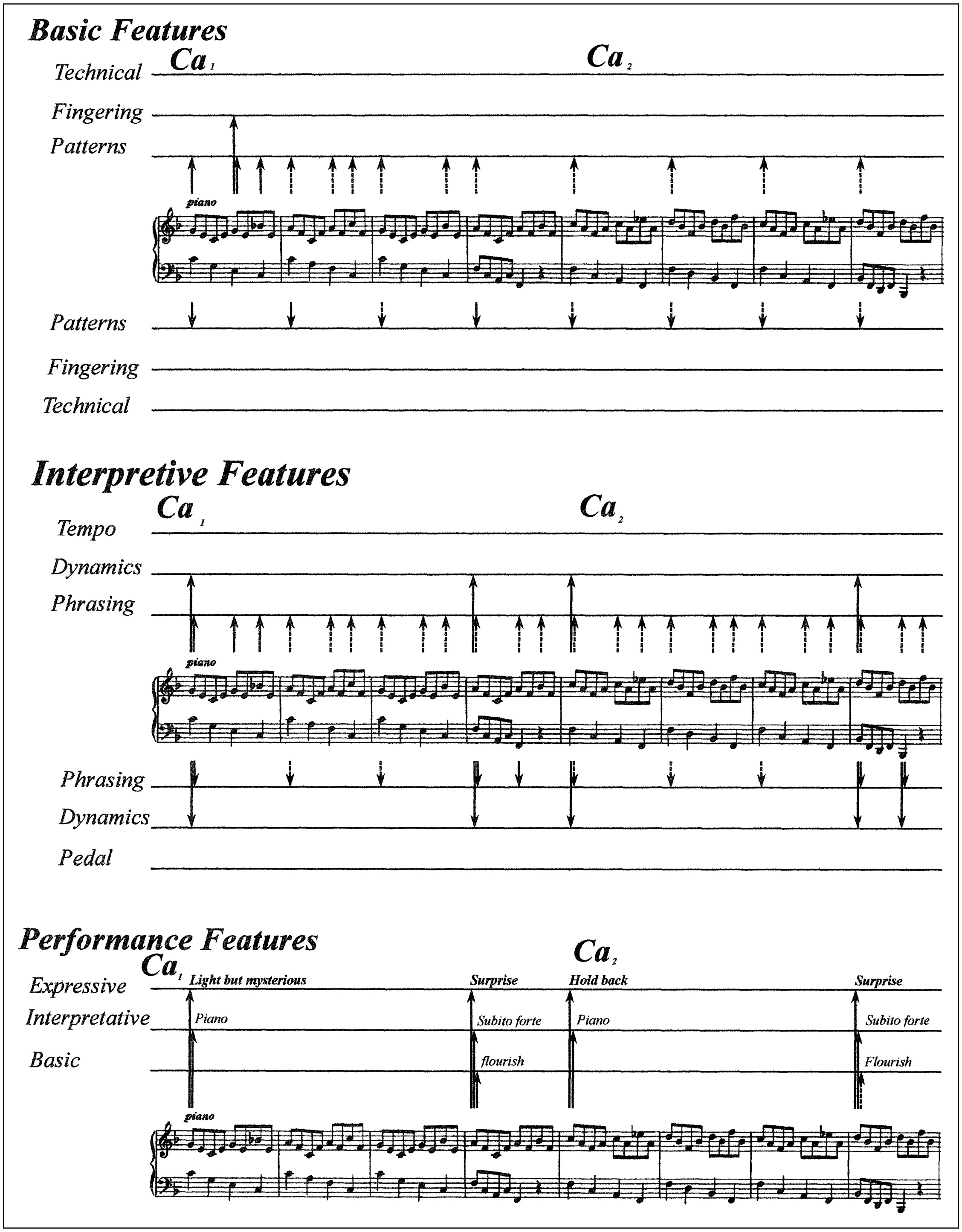

Fig. 2. The features of the music (indicated by arrows) that the pianist reported attending to during practice for subsections Ca_1 and Ca_2 of the *Presto*. Number of features per bar on each of the 10 dimensions served as a predictor of practice and recall.

than at other locations in Period 1, during initial memorization, and in Period 3, when a decision to increase the tempo meant that retrieval from long-term memory was again too slow to keep up with the motor performance.

Performance cues

Performance cues were also a focus of practice throughout the learning process. Practice segments started at basic performance cues

Table 2. *Regression coefficients and* R^2 *for the effects of musical structure, performance cues, and basic and interpretive dimensions on number of repetitions, starts, and stops during practice*

	Learning Period 1			Learning Period 2			Learning Period 3		
Predictor variable	Repetitions	Starts	Stops	Repetitions	Starts	Stops	Repetitions	Starts	Stops
Musical structure									
Begin section	22.94	17.58***	10.14*	5.83	6.16***	1.84	18.46	8.93**	1.21
End section	4.47	4.08	2.48	−2.69	1.61	2.45**	−8.00	−0.76	3.99*
Serial position	1.84	0.19	0.11	1.34***	−0.11	−0.15	3.99***	−0.06	−0.13
Switch	10.85	5.39	4.84*	−0.71	0.92	0.07	8.47	2.60	4.03***
Performance cues									
Basic	7.71	5.96*	5.14*	8.43***	1.15	0.81	−9.88	−1.08	−0.8
Interpretive	1.46	5.61	5.32*	10.45***	1.29	2.09**	14.15*	2.08	0.91
Expressive	−9.26	4.75	−2.17	−8.15**	0.58	−1.55	−8.16	0.67	−1.60
Basic dimensions									
Fingering	10.43**	0.99	1.33	2.96**	0.55	0.43	5.05*	0.25	1.03*
Technical	11.79**	5.01**	4.07**	2.09	0.38	−0.35	5.60	1.09	0.94
Familiar patterns	3.75	0.43	1.31	1.19	0.32	0.21	1.78	0.16	0.24
Interpretive dimensions									
Phrasing	−3.25	0.33	−1.03	1.20	0.15	−0.24	−0.49	−0.60	−0.47
Dynamics	1.13	−2.79	−3.00*	−3.41*	−0.53	−0.94*	−9.65**	−0.75	−1.05
Tempo	−30.49	−19.99*	−10.53	−2.20	−3.49	1.69	1.55	−1.29	1.64
Pedal	−6.61	−1.84	4.29	−3.11	−0.07	−0.13	−8.11	−1.48	−2.25
Number of notes	−1.52	−0.44	−0.09	0.09	−0.07	0.25	−1.28	−0.52	−0.36
R^2	.23***	.36***	.29***	.40***	.28***	.17***	.19***	.17***	.17***

$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

and stopped at basic and interpretive performance cues more than at other locations in Learning Period 1. The effect of interpretive cues on stops continued in Period 2, suggesting that these retrieval cues were still not operating up to speed. At the same time, a new form of practice appeared in Period 2, as the pianist committed the music to memory. Bars containing basic and interpretive performance cues were repeated more, indicating that they were being played as part of longer passages, not just serving as starting places. This provided practice at memory retrieval under the time pressure of performance. For interpretive cues, this form of practice continued in Period 3.

Expressive performance cues also affected practice during Learning Period 2, but unlike basic and interpretive performance cues, expressive cues had a negative effect—they were repeated less often than other bars. Negative effects on practice appear to be a hallmark of features representing change—of expression, dynamics, or tempo. Changes must be practiced by playing through the transition without stopping, producing negative effects.

Basic and interpretive dimensions

Fingerings and dynamics required practice in all three learning periods, whereas effects of technical difficulties and tempo were confined to Period 1. There was no effect of familiar patterns, and thus no evidence that availability of prestored chunks affected practice. Despite the absence of this effect, the pianist's comments during the early sessions indicated that she found familiar patterns helpful (Chaffin, Imreh, & Crawford, 2002, chap. 6).

In summary, extended practice of memory retrieval is indicated by the practice of locations where retrieval from long-term memory would be expected to occur. This conclusion is strengthened by examination of hesitations when the pianist began to play from memory.

Memory Runs

The pianist's initial attempts to play from memory were full of hesitations, as she struggled to remember what came next. The tempo fluctuated between the *target tempo*, which reappeared repeatedly, and slower, more varied tempi. Table 3 shows estimates of how much time was spent in hesitation, by comparing the observed playing time for each run with the expected playing time based on the target tempo. The difference is the *additional playing time.* Expressed as a percentage of expected playing time, additional playing time indicates the proportion of each memory run spent in hesitation. Hesitations added between 18% and 65% to playing time. The possibility that some of this additional time might have been due to deliberate, expressive slowing was ruled out by making the same measurements for the performance on the CD, for which observed and predicted playing times were almost identical.

To discover where the hesitations occurred, we submitted the IBIs for memory runs to multiple regression analysis (see Table 4; de Vries, 1999). Hesitations occurred at performance cues and at the ends of sections. IBIs were longer in bars containing basic performance cues in all three memory runs, at interpretive performance cues in Runs 8.1 and 12.1, and at expressive cues in Run 12.2. There were no effects of performance cues on the CD performance, so these were not deliberate, expressive effects. It appears that performance cues were functioning as retrieval cues and that, in the initial attempts to play from memory, retrieval was often too slow to keep up with the performance.

Table 3. *Observed playing time and target tempo for memory runs and the final performance and comparison with expected playing time*

Temporal measure	Practice (memory runs) Run 8.1	Run 12.1	Run 12.2	Final performance (CD)
Playing time	5:01	5:53	4:13	3:04
Target tempo (beats/min)	116	118	118	138
Expected playing time[a]	3:37	3:34	3:34	3:03
Additional playing time (observed − expected)	1:24	2:19	0:39	0:01
% additional playing time (additional/expected *100)	38.7	64.9	18.2	0.0

[a]Calculated as the total number of beats (420: 210 bars × 2 beats per bar) divided by the target tempo.

IBIs were also longer at the ends of sections, as the pianist retrieved the next section from memory. IBIs were longer for the last bar of the section in Run 12.1, and for bars later in a section in Runs 12.1 and 12.2 (the effects of serial position). Slowing at the ends of sections is a common interpretive device, and these effects could have been deliberate. However, they did not appear in the CD performance, so it is likely that the pianist was using interpretive slowing to allow more time to recall the next section.

Switches were played more quickly than other bars in Run 8.1, suggesting that they affected retrieval. The effect is, however, opposite to the one expected. The pianist may have known that she would have trouble at switches and so glanced at the score. Alternatively, she may have paid extra attention to switches in practice, making them more fluent than other bars.

There were no effects for the basic dimensions. This is important because it indicates that hesitations were not due to problems with fingering and technical difficulties. Mechanical problems with “finger tangles” are, however, the likely explanation for the effect of number of notes in Run 8.1. The negative effects of dynamics in Run 8.1 and phrasing in Run 12.2 indicate speeding up, not hesitation, and are probably not due to retrieval problems.

Free Recall After 27 Months

Location in the formal structure and performance cues together provided a very good account of why some bars were remembered better than others, accounting for 76% of the variance in recall (Table 5). The effect of serial position evident in the regression analysis sum-

Table 4. *Regression coefficients and* R^2 *for the effects of musical structure, performance cues, and basic and interpretive dimensions on interbar intervals for practice runs from memory and the final performance*

Predictor variable	Practice (memory runs) Run 8.1	Run 12.1	Run 12.2	Final performance (CD)
Musical structure				
Begin section	−0.07	0.07	−0.03	−0.06*
End section	0.10	0.15*	0.05	0.01
Serial position	0.01	0.02*	0.01*	0.00
Switch	−0.16*	0.04	0.00	0.01
Performance cues				
Basic	0.27***	0.09*	0.11***	0.02
Interpretive	0.14*	0.10*	−0.02	−0.01
Expressive	0.09	−0.02	0.07*	0.03
Basic dimensions				
Fingering	0.00	−0.04	−0.00	−0.01
Technical	0.04	0.01	0.01	0.00
Familiar patterns	−0.00	0.03	0.01	0.01
Interpretive dimensions				
Phrasing	0.00	−0.02	−0.02*	−0.00
Dynamics	−0.13**	−0.04	−0.02	−0.00
Tempo	0.22	0.17	0.07	0.14***
Pedal	0.00	−0.01	−0.01	0.05***
Number of notes	0.04*	0.01	0.00	−0.01**
R^2	.27***	.19***	.27***	.25***

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

Table 5. *Regression coefficients and* R^2 *for the effects of musical structure and performance cues on probability of recall*

Predictor variable	Regression coefficient
Musical structure	
Serial position	−0.15***
Begin section	−0.03
End section	0.47***
Performance cues	
Basic	−0.28**
Interpretive	−0.01
Expressive	0.24**
R^2	.76***

** $p < .01$. *** $p < .001$.

Table 6. *Mean probability of correct recall as a function of serial position from section boundaries and from performance cues*

	Serial Position				
Predictor variable	1	2	3	4	5–8
Section boundaries	.97	.90	.87	.69	.28
	(6)	(6)	(6)	(6)	(1–2)
Performance cues					
Expressive	.85	.85	.74	.43	.00
	(11)	(10)	(5)	(3)	(3)
Basic	.68	.77	.78	.77	.46
	(11)	(7)	(6)	(5)	(3)
Interpretive	.75	.78	.61	.00	—
	(19)	(8)	(4)	(1)	(0)

Note. For each combination of predictor variable and serial position, the number of bars is shown in parentheses.

marized in Table 5 is shown more directly in the first row of Table 6. The first bar in a section was recalled best, with recall declining in successive bars, $F(4, 27) = 8.84$, $p < .001$. The effect suggests that the pianist's memory was organized into chunks based on the sections of the formal structure and that retrieval of each section began with the first bar, with each bar cuing recall of the next (Fischler, Rundus, & Atkinson, 1970; Rundus, 1971).

The regression analysis also showed effects of two performance dimensions (Table 5). Recall of bars containing expressive performance cues was better than recall of other bars, whereas recall of bars containing basic performance cues was worse. The positive effect of the expressive cues indicates that they were effective retrieval cues. The negative effect of basic performance cues, in contrast, suggests that attention to basic performance cues came at the expense of other details.

Why would basic and expressive performance cues affect recall in opposite ways? Because they play different roles. Basic performance cues ensure the execution of critical movements, such as the placement of a particular finger. Attention to details of this sort leaves fewer attentional resources for other features, resulting in poorer recall. Attention to expressive cues, however, does not come at the expense of other features. Rather, an expressive cue encapsulates or chunks a passage in the same way that a section does. Just as thinking of a section activates its more detailed representation, thinking of an expressive cue activates details of the expressive phrase. Bars containing expressive cues were recalled better than other bars because these bars were activated most strongly by the retrieval cue.

This implies that expressive performance cues should show a serial-position effect similar to that for section boundaries. Table 6 (row 2) presents the mean probability of recall as a function of serial order of bars numbered successively from each expressive performance cue. As predicted, there was a serial-position effect: The first two bars in an expressive phrase were recalled best, and succeeding bars were recalled successively less well, $F(4, 27) = 8.39$, $p < .001$. Table 6 also shows the same analysis for basic and interpretive performance cues. There was no serial-position effect for basic performance cues, $F < 1.0$, and the apparent trend for interpretive performance cues was not significant, $F < 1.8$.

This examination of serial-order effects further confirms that basic and expressive performance cues affected retrieval differently and shows that expressive cues functioned in the same way as sections and subsections. Expressive cues appear to represent the next level in the retrieval hierarchy, dividing subsections into expressive phrases (see Fig. 1). This supports the pianist's claim that she practiced thinking of expressive cues while polishing the piece for performance. She apparently rechunked the piece, creating a new layer of cues in the retrieval hierarchy. These expressive cues came automatically to mind during performance, eliciting the necessary motor responses, while allowing her to attend to expressive goals.

CONCLUSIONS

Concert pianists provide an interesting test of the principles of expert memory (Ericsson & Kintsch, 1995) because they make their living performing from memory. Like expert memorists in other fields, the concert pianist in our study engaged in extended practice in the use of a retrieval scheme to ensure that recall occurred rapidly and automatically. This reliance on conceptual memory is somewhat surprising, given the importance of motor and auditory memory in piano performance. However, the pianist went to great lengths to ensure that she could rely on conceptual memory in addition to motor and auditory memory. The formal structure of the music provided a hierarchical retrieval structure, organized into sections and subsections, with expressive phrases containing basic and interpretive performance cues and switches making up the bottom levels (Fig. 1). The pianist engaged in prolonged practice to bring the operation of this retrieval scheme up to the pace of the motor performance. This conceptual representation allowed the pianist to focus on expressive goals during performance, while also keeping track of where she was so that she did not take a wrong turn at a switch. If she did take a wrong turn, the conceptual representation provided a means to recover.

Ideally, the pianist plays with the expressive cues in the spotlight of attention against a background of basic and interpretive performance cues and structural knowledge. When this happens the performer experiences "flow" (Csikszentmihalyi & Csikszentmihalyi, 1988), a trancelike state in which "the notes have become you and you have become the notes" (Ivo Pogorelich, quoted in Mach, 1980, 1988/1991, Vol. 2, p. 244). But each performance is different, and on another occasion a performer may have to work hard to keep things on track.

This is when the basic and interpretive performance cues are called into play.

This study extends the principles of expert memory from domains that rely almost entirely on conceptual memory, like memory for chess and digit strings. The use of conceptual memory to guide skilled motor performance may be a hallmark of expertise in domains such as musical performance and dance, which involve both complex motor skills and aesthetic sensibility.

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REFERENCES

Aiello, R. (2000, August). *Playing the piano by heart*. Poster presented at the Biological Foundations of Music Conference, The Rockefeller University, New York.

Broadbent, D.E., Cooper, P.J., & Broadbent, M.H. (1978). A comparison of hierarchical matrix retrieval schemes in recall. *Journal of Experimental Psychology: Human Learning and Memory*, *4*, 486–497.

Chaffin, R., & Imreh, G. (1997). “Pulling teeth and torture”: Musical memory and problem solving. *Thinking & Reasoning*, *3*, 315–336.

Chaffin, R., & Imreh, G. (2001). A comparison of practice and self-report as sources of information about the goals of expert practice. *Psychology of Music*, *29*, 39–69.

Chaffin, R., Imreh, G., & Crawford, M. (2002). *Practicing perfection: Memory and piano performance*. Mahwah, NJ: Erlbaum.

Chase, W.G., & Ericsson, K.A. (1982). Skilled and working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 16, pp. 1–58). New York: Academic Press.

Chase, W.G., & Simon, H.A. (1973). Perception in chess. *Cognitive Psychology*, *4*, 55–81.

Cooke, J.F. (1999). *Great pianists on piano playing: Godowsky, Hofmann, Lhevinne, Paderewski and 24 other legendary performers*. Toronto, Ontario, Canada: Dover. (Original work published 1913)

Csikszentmihalyi, M., & Csikszentmihalyi, I.S. (1988). *Optimal experience: Psychological studies of flow in consciousness*. New York: Cambridge University Press.

de Vries, H. (1999). *Bar duration as a measure of memory organization: Exploring skilled memory in a concert pianist*. Unpublished honors thesis, The College of New Jersey, Hillwood Lakes, NJ.

Ericsson, K.A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*, 211–245.

Ericsson, K.A., & Oliver, W.L. (1989). A methodology for assessing the detailed structure of memory skills. In A.M. Colley & J.R. Beech (Eds.), *Acquisition and performance of cognitive skills* (pp. 193–215). Chichester, England: Wiley.

Fischler, I., Rundus, D., & Atkinson, R.C. (1970). Effects of overt rehearsal procedures on free recall. *Psychonomic Science*, *19*, 249–250.

Halpern, A.R., & Bower, G.H. (1982). Musical expertise and melodic structure in memory for musical notation. *American Journal of Psychology*, *95*, 31–50.

Hinson, M. (1987). *Guide to the pianist’s repertoire* (2nd ed.). Bloomington: Indiana University Press.

Imreh, G. (Pianist). (1996). *J.S. Bach* [CD]. New York: Connoisseur Society. (Available from Gabriela Imreh, Gabrielaimreh@aol.com)

Mach, E. (1991). *Great contemporary pianists speak for themselves*. New York: Dover. (Original work published in two volumes, 1980 and 1988)

Mandler, G., & Pearlstone, Z. (1966). Free and constrained concept learning and subsequent recall. *Journal of Verbal Learning and Verbal Behavior*, *5*, 126–131.

Miklaszewski, K. (1989). A case study of a pianist preparing a musical performance. *Psychology of Music*, *17*, 95–109.

Miklaszewski, K. (1995). Individual differences in preparing a musical composition for public performance. In *Psychology of music today: Proceedings of the International Seminar of Researchers and Lecturers in the Psychology of Music* (pp. 138–147). Warsaw, Poland: Fryderyk Chopin Academy of Music.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*, 81–97.

Roediger, H.L., III, & Crowder, R.C. (1976). A serial position effect in recall of United States Presidents. *Bulletin of the Psychonomic Society*, *8*, 275–278.

Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*, *89*, 63–77.

Thompson, C.P., Cowan, T.M., & Frieman, J. (1993). *Memory search by a memorist*. Hillsdale, NJ: Erlbaum.

Tulving, E. (1962). Subjective organization in free recall of “unrelated” words. *Psychological Review*, *69*, 344–354.

Williamon, A., & Valentine, E. (2002). The role of retrieval structures in memorizing music. *Cognitive Psychology*, *44*, 1–32.

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