Mental Practice in Music Memorization: An Ecological-Empirical Study

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The present study aims to systematically describe mental practice (MP) in music memorization, with regard to individual differences in the use of different MP strategies and their performance outcomes. Sixteen pianists were studied while they memorized piano pieces. Each subject memorized two pieces, either via MP or physical practice (PP). In order to keep the setting as ecologically valid as possible within the experimental setup, we allowed subjects to freely apply their preferred MP strategies with the exception of physically playing a real piano. Practice and performances were video documented and expert rated; practice strategies were reported in researcher-developed questionnaires. The use of MP alone led to successful music learning. MP combined with PP produced results that were indistinguishable from those following PP alone. Pitch imagery and structural analysis were associated with better post-MP performance. Results are discussed in the frame of expert memory theory (Chase & Simon, 1973; Chaffin, Logan, & Begosh, 2009) and practical implications for musicians are provided.

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Mental practice (MP) is generally defined as a technique by which someone with the intent to practice creates a mental representation of a preconceived idea or action in order to enhance performance (van Meer & Theunissen, 2009). The focus of the present study is on performance enhancing rehearsal strategies, which must be distinguished from other techniques of emotional and mental training for performance preparation (e.g., relaxation training, meditation, visualization of prescribed images; see Connolly & Williamon, 2004, for a review).

MP has been investigated as a potentially useful practice technique in different fields, including athletics (Feltz & Landers, 1983), stroke rehabilitation (Zimmermann-Schlatter, Schuster, Puhan, Siekierka, & Steurer, 2008) and music (Cahn, 2008; Theiler & Lippman, 1995). Converging evidence from different fields has shown that MP has a moderate and significant impact on performance, and that the effects of MP are weaker than the effects of physical practice (PP) (Gabrielsson, 1999). The efficacy of MP increases when the task involves cognitive or symbolic skills and when the subject has expertise in the specific task's domain (Driskell, Copper, & Moran, 1994). Moreover, several studies have shown that proper combinations of MP and PP may lead to results that are close to or equal to those obtained in PP alone (Feltz, Landers, & Becker, 1988; Kopiez, 1990). Music performance serves as an excellent model for studying MP because it is made up of tasks with complex cognitive elements (to a greater extent than in sport performance). At the same time, for a musician, performance is something that is natural to provide (thus, being ecologically valid) and for a scientist the performance is an output that can be objectively measured. Yet, up to now, few research studies have specifically tested the effectiveness of MP in music performance. In the field of music performance, MP has been used and taught at least since the contribution of the well-known piano teacher Karl Leimer and his most famous pupil Walter Gieseking (Barry & McArthur, 1994; Leimer & Gieseking, 1998; McMillan, 2005). According to Leimer, through the use of MP "... the piece can be perfectly performed and this in a most astonishingly shorter time" (Leimer & Gieseking,

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1998). MP techniques for musicians include conducting a formal analysis of the score, listening to a recording of the piece, forming auditory imagery of the pitches, imagining movement (visually and/or kinaesthetically) and using visual imagery of the score (Klöppel, 1996; Orloff-Tschekorsky, 1996).

Overall, results of empirical studies on musicians show that MP is more effective than no practice and not as effective as PP in terms of both objective measurements (e.g., correctness of notes) and expressive features (Highben & Palmer, 2004; Lim & Lippman, 1991). Still, it has also been shown that MP alone may lead to the same plastic changes in the motor system as those occurring with the acquisition of the skill by repeated PP (Pascual-Leone et al., 1995). MP used along with an auditory model showed better results than MP alone (Lim & Lippman, 1991; Theiler & Lippman, 1995). The combination of MP and PP appeared to be particularly effective in the field of music, as shown by several experiments using different tasks and instrumentalist groups (Cahn, 2008; Coffman, 1990; Kopiez, 1990; Ross, 1985; Theiler & Lippman, 1995). Depending on the task, the use of MP and PP led to performances that were as close to, or even indistinguishable from, those following PP alone (Theiler & Lippman, 1995).

However, all these results come from highly controlled experimental situations that have imposed severe constraints on the practice situation and/or the subjects. First, subjects were always forced to use a specific MP strategy that was chosen by the experimenter independently from task and individual-related features. In fact, MP has been reduced to: a) an analytical pre-study of the score, or listening to a recording of the piece followed by analytical study (Rubin-Rabson, 1937); b) auditory plus kinesthetic imagery (Cahn 2008; Ross, 1985); c) imagery of sounds while pressing silent keys, or imagery of the feeling of the movements while actually hearing the sounds, or auditory plus kinesthetic imagery in the absence of any feedback (Highben & Palmer, 2004); d) visual plus kinesthetic imagery with an auditory model (Coffman, 1990); or e) visual plus auditory plus kinesthetic imagery, with or without an auditory model (Coffman, 1990; Lim & Lippman, 1991; Ross, 1985; Theiler & Lippman, 1995). Second, subjects were often asked to practice in unnatural situations: Depending on the study, subjects had to avoid MP strategies other then the one prescribed (Highben & Palmer, 2004). For example, they had to avoid any overt movement of the hand/fingers (Cahn, 2008; Coffman, 1990; Ross, 1985) or humming (Lim & Lippman, 1991; Ross, 1985). In some studies MP included a recorded version of the piece played at fixed time intervals (Theiler & Lippman, 1995) or even played continuously for the entire practice time (Coffman, 1990; Highben & Palmer, 2004; Lim & Lippman, 1991). In other studies, participants had a very limited time window (e.g., three minutes) to implement their MP (Cahn, 2008; Coffman, 1990) or had to practice the piece a fixed number of times without stopping or correcting mistakes (Coffman, 1990; Highben & Palmer, 2004; Ross, 1985).

The above mentioned constraints were introduced in order to improve experimental control, and these controlled studies yielded valuable and converging results, indeed. However, these constraints may have significantly altered the MP processes from what they are in a musician's daily life, thereby producing partially ambiguous or biased results. Encouraging or forcing a musician to use a specific MP strategy potentially raises the following problems:

I. In methodological terms, it is often not clear why the experimenter has a priori decided to select one strategy and not another. Inclusions and exclusions of MP strategies in the previously mentioned studies seem to be partially guided by the author's implicit or explicit assumptions about which strategies constitute the very core of MP. Yet there is no consensus among scientists about the exact nature of these core processes. Furthermore, such a debate would not be particularly relevant for the musician, who appreciates MP as a heterogeneous and flexible tool.

II. Such experiments do not take into account how much the selected strategy conforms to each subject's preferences, habits, and abilities (individual-related features). For example, both Lim and Lippman (1991) and Highben and Palmer (2004) speculated about the existence of individual MP-related features that could have an important role in the way MP was applied. In fact, many of Lim and Lippman's subjects expressed the desire for more freedom in the application of MP, while Highben and Palmer documented an association between individual performers' musical memory and imagery skills (auditory vs. motor).

III. Maintaining the same strategy throughout the whole practice process does not allow the subjects to flexibly change their approach in order to optimize the learning process or manage specific elements of the task that might benefit from different MP tactics (task-related features). Comparing the performance of guitarists and vocalists, Theiler and Lippman (1995) concluded that "features of MP regimen should be adjusted to accommodate particular applications, because different attributes may be optimal for various physical and musical endeavors."

IV. The demand of using only one MP strategy to the exclusion of all others appears to be unrealistic for musicians. This can be nicely illustrated by taking the underlying brain mechanisms into account. Several neuroimaging studies have described the tight and automatic coupling between auditory, visual, and motor networks in the brains of musicians (Haslinger et al., 2005) and even of naïve subjects following just 20 minutes of piano training (Bangert & Altenmüller, 2003). It is not likely that all of these tight and long-term developed connections can be effectively interrupted by the subject's conscious will. Lim and Lippman's (1991) results underlie this hypothesis, since "all subjects found it almost impossible to separate the kinaesthetic image from the visualization of 'hands on keyboard'; two of the subjects claimed that musicians automatically listen to music and feel their instrument tactually" (p. 27).

Consequently, the experimental control of a study design that focuses on a specific MP strategy remains doubtful, especially when attempting to identify individual differences in: a) how effectively undesired MP strategies have been switched off; b) the cognitive cost paid for this switching off; c) the practice strategy actually used; and d) preferences, habits, and abilities in the strategy actually applied.

The present study was primarily designed to address these limitations. We therefore designed an "open" MP condition in which the participants were completely free to use any MP strategy they desired without any constraint and within an amount of time close to the one indicated in past research as the most effective for MP (Driskell et al., 1994). We allowed participants, for example, to move fingers and hands without the instrument, since this is a commonly used MP strategy. Furthermore, this strategy is explicitly recommended in practical guides to MP in sports (Rushall, 1991). Thus, a higher degree of ecological validity enables the present investigation to ask questions, such as:

I. Are certain MP patterns more effective than others?

II. Is MP more effective when it is freely used than when it is constrained, as in previous studies? Converging evidence has shown that the effectiveness of skill learning can be enhanced if the learner is given some control over the practice conditions (Chen, Hendrick, & Lidor, 2002; Chiviacowsky & Wulf, 2002; Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997).

For the present investigation, a music memorization paradigm was chosen because of its potential implications in both applied and theoretical terms. To begin with, memorization is a major issue for musicians; playing from memory is often a source of anxiety and memorization still tends to be seen as an individual and mysterious process, in which each person has to find his or her own method (Ginsborg, 2002). A deeper and systematic knowledge of the means to improve music memorization abilities could therefore have practical applications in the field.

Moreover, Chaffin and collaborators have shown that the main principles described by expert memory theory in classic domains (e.g., chess, see Chase & Simon, 1973; digit strings, see Thompson, Cowan, & Friedman, 1993) rule the behavior of expert musical memorists also, specifically a) the meaningful encoding of novel material; b) the use of a well-learned retrieval structure; and c) extended practice to decrease the time needed for retrieval from long-term memory (Chaffin, Logan, & Begosh, 2009; Ericsson & Kintsch, 1995). Of particular interest is the finding that music performance from memory relies heavily on structural and linguistic memory, in addition to auditory and motor memory. First, expert musicians rely on schematic knowledge already stored in memory to organize information into larger chunks. Second, they use a retrieval scheme to organize the cues that provide access to the chunks of information in long-term memory. Musicians' schematic structures can be identified as familiar patterns such as chords, scales, and arpeggios, while the formal structure of the music conveniently provides a ready made hierarchical organization to serve as a retrieval scheme (Chaffin & Imreh, 2002). These conclusions come from studies in which the piano was always available to the musician; therefore, it would be interesting to see how memorizing strategies are applied and adapted when the physical feedbacks of the real action are not available. For example, movement simulation has been shown to support operations such as letter recall from memory in deaf children (Locke & Locke, 1971) or abacus calculation in expert abacus operators when the abacus was not available (Hatano & Miyake, 1977). Interestingly, this form of "transitional" sensory representation appeared linked with

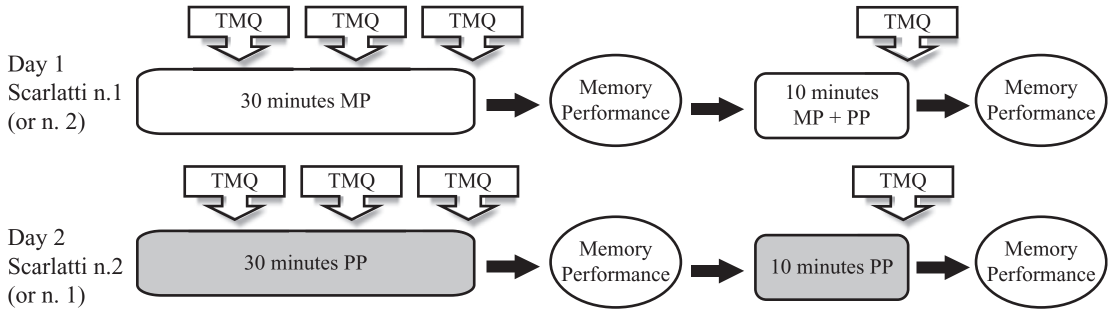

FIGURE 1. Experimental design.
Note. MP = Mental Practice. PP = Physical Practice. TMQ = Ten Minute Questionnaire, administered during practice, aimed at describing the mental strategies being used.

the degree of expertise, with more advanced subjects being able to avoid it (Hatano & Miyake, 1977).

Based on these considerations, we generated hypotheses about the features and strategies that are more predictive of successful performance. Considering that our subjects had to prepare a memorized performance of a relatively simple piece of music using MP, we hypothesized that: 1) Structural/formal analysis of the piece would be associated with better performance. 2) Pitch imagery would be strongly connected with performance results; in fact, in MP pitch imagery is likely to be a core operation, not a transitional one, acting as a prerequisite for structural analysis or other higher-order operations. Auditory memory-based operations might become less relevant when the piano is available. 3) Motor and visual imagery should play a minor role. It would also be possible to observe differences in the role of motor and visual imagery between subjects with low vs. high motor/visual imagery capabilities. 4) Subjects' listening to the auditory model would be associated with poorer performance. Compared with past studies showing the advantage of auditory model-supported MP vs. MP without this kind of support, in the present study subjects could choose whether to listen to the recording or not. Following the reasoning of Hatano and Miyake (1977), it seems likely that more advanced subjects would not "waste" resources in this transitional operation. 5) For the same reasons, the subjects' moving of fingers should be associated with poorer performance.

Method

PARTICIPANTS

Sixteen right-handed pianists (8 males, 8 females) were recruited on a volunteer basis from the University of Music and Drama, Hannover, Germany. They had a mean age of 26 $\pm$ 4 years (range = 18 to 36) and they had at least 15 years of individual piano instruction (mean = 20 $\pm$ 4; range = 15 to 26). In an initial questionnaire (see Results), all subjects reported being familiar with MP skills and strategies.

MATERIALS

The first half of two Domenico Scarlatti sonatas of comparable length and difficulty were selected (see Appendix for excerpts from the score of the two pieces, Supplementary Figure 1 and Supplementary Figure 2). The pieces were slightly modified to have the highest degree of comparability without altering the original musical context. As a result of these manipulations, the excerpt of the C major sonata (K 72) included a total number of 387 notes, while the excerpt of the A major (K 113) included 385; both pieces included 19 bars, 48 four-semiquaver groups in the right hand, 20 four-semiquaver groups in the left hand (a four-semiquaver group consists of four successive semiquaver notes). In both pieces, eight of these four-semiquaver groups were identically repeated. In the C major sonata excerpt there were 49 octave notes in the left hand and 54 in the A major sonata excerpt. Although there was a high similarity in the general structural form, the two pieces still had several subtle differences; for example, the complexity of the four-semiquaver groups was slightly higher for the A major sonata excerpt. These differences were preserved to avoid interferences between the two pieces, but were leveled due to balanced assignment to the two practice conditions. During performance, as well as during PP, subjects played on a Wersi Digital Piano CT2 (Halsenbach, Germany) using the standard piano timbre. All practice sessions and performances were video documented by a digital video camera from a standardized position that revealed the profile of the pianists.

DESIGN

Each subject was asked to learn the two pieces, one via MP (see the Appendix for a list of abbreviations) and the other via PP, on two different days (see Figure 1 for a brief summary of the design). After the practice session, the piece had to be performed by memory. Because of the focus on the memorization paradigm, we selected two highly comparable music excerpts that had no specific technical difficulties (which would have brought an uncontrolled source of variability between subjects); such pieces would have been too easily sight-read in a non-memory performance task. A certain degree of experimental control was therefore maintained in this component of our design.

The assignment of the two pieces to each condition (MP or PP) was counterbalanced between the subjects so that half of the sample studied the A major sonata excerpt using MP and the C major sonata using PP, and the other half studied the A major sonata using PP and the C major sonata using MP. Half of the sample had the MP trial on the first day; the other half on the second day. The time interval between the two study days was on average 5 days. Subjects were randomly assigned to their respective protocols.

PROCEDURE

Before entering the study, subjects confirmed that they did not know the two musical pieces and filled out a questionnaire assessing their familiarity with MP strategies. This questionnaire was divided into six sections regarding registry information, MP-abilities, MP-habits, MP strategies for music memorization, external resources, and solfège. Apart from registry information, each section contained statements (e.g., "Is mental visualization of the score of a piece useful for you in the memorization of the music?") that had to be rated on a Likert scale ("1" = "never"/"not at all"/"absolutely not" to "10" = "always"/"perfectly"/"absolutely").

Subjects using MP on the first day were allowed some time to freely familiarize themselves with the MIDI piano before the start of the experiment. This was done to avoid unexpected discomfort when playing on an unfamiliar instrument following MP. For both, MP and PP, a metronome indicated a speed of 80 bpm prior to the start of the practice session. Subjects were asked to adjust the tempo of their final performance to this speed. During MP, subjects were seated comfortably in front of a table with the score of the piece to be studied and a pencil. Instructions for the use of MP were as follows: "You can freely use whatever practice method you prefer, except for physically playing a real piano." A MIDI recording of the piece was also available to the subjects, who were free to listen to it and to pause and resume it as many times as they wished. Subjects were allowed to write on the score as well as to move their fingers.

During PP subjects sat in front of the MIDI piano. Instructions for the use of PP were as follows: "We ask you to focus on physically practicing the piece, ignoring any mental images you have as you practice. Do not to stop to mentally rehearse the music and avoid formal analysis of the piece." In our view, the definition of PP as a control condition represents a crucial point of methodology. In past research, some studies (Lim & Lippman, 1991; Theiler & Lippman, 1995) required subjects to avoid imagery operations during PP, assuming PP as a "pure" task, complementary to MP. Other studies (Ross, 1985; Coffman, 1990; Cahn, 2008) did not provide any definition of PP, leaving unclear to what extent imagery operations were allowed or not. Only Lim and Lippman (1991) controlled the degree of imagery operations actually implemented during PP, finding that "when given auditory or visual information, or when making actual movements, it was impossible to form an image." Even if empirically supported, this result is somewhat disputable: The authors reported that in their own study "the sophistication of the subjects appears to have been overestimated" and that a "more sophisticated screening of participants may be necessary, in pursuit of those having highly developed or better practiced imaging skills" (Lim & Lippman, 1991). In the present study, the "pure PP" control task was employed in order to have past research as a clear reference point. To assess how often participants relied on different imagery and mental strategies during MP as well as during PP, we developed a short questionnaire (see below) that was administered from time to time during both MP and PP.

Under both conditions—that is, using MP and PP—subjects had 30 min (Phase 1-3, each phase with a 10-min duration) to study the respective piece; subsequently, they had to perform the piece on the MIDI piano by memory twice. Following these two performances, subjects had 10 min (Phase 4) to continue studying the same piece. Subjects who had previously studied the piece using MP were now free to combine mental strategies with real piano playing (MP+PP); subjects who had previously studied the piece using physical practice were asked to keep on practicing in the same way, thus avoiding mental rehearsal, imagery, or formal analysis (PP+PP). Finally, the subjects again performed by memory twice. For all conditions, subjects were not forced to memorize the whole piece; while performing, they were free to play as far as they could, but they were explicitly asked to give a performance coherent with the score, thus avoiding improvisation, repetitions, or jumping between different bars of the piece.

MEASUREMENTS

During all practice conditions, after each phase (i.e., every 10 min) subjects were asked to fill out a short questionnaire (Ten Minute Questionnaire; TMQ) documenting the mental strategies they may have used. Subjects had to rate on a Likert-scale from "1" ("not at all") to "5" ("very often") how often they used the following strategies: mentally hearing the sound of notes, mentally feeling the movement of fingers/hands, mentally visualizing the movements of fingers/hands, mentally visualizing the score, harmonic analysis of the piece, rhythmical analysis of the piece, melodic analysis of the piece." The TMQ was validated by running a pretest with a sample of 38 professional musicians (the expertise as professional musician always being greater than 4 years). Participants were asked to rate each item of the TMQ questionnaire assessing both clarity and relevance of each question on a 5-point scale ("1" = "very low" to "5" = "very high"). Overall clarity and usefulness of the instrument was investigated as well. A questionnaire similar to TMQ, without the harmonic/rhythmical/melodic questions, was administered after the performance, to reconstruct which mental strategies were used while performing. Following the last performance after Phase 4, a short interview was conducted to reconstruct—this time by free recall—which strategies were used during the 40 min of practice and how thoroughly the piece had been formally analyzed. All participants confirmed that the pieces did not contain any sequence difficult to play and that the main challenge of the task was just to memorize the notes.

At the end of the session, a test for musical auditory imagery was administered. We developed a test based on the task described by Highben and Palmer (2004) to investigate auditory imagery in mental practice research: Participants were shown the score of a single-line melody (9-12 pitches) and simultaneously heard a melody, which was the same as the notated melody or had a difference of one pitch. The stimuli were adjusted by making the one-note difference a change of 1-2 semitones; the total number of changes that moved up or down in pitch were balanced. Twelve of the 16 melodies presented had a one-note difference. The 16 melodies were played via loudspeakers, and subjects were asked to identify any pitch differences between the melodies presented by loudspeaker and the ones presented on the scores. The internal consistency of this test was assessed by computing Cronbach's alpha on the data collected in a pretest with a sample of 20 musicians (the expertise as professional musician always being greater than 4 years).

Individual differences in mental imagery were tested by administering the standardized questionnaires USOIMM77 (Antonietti & Colombo, 1996-1997), Motor Imagery Questionnaire-Revised (Hall & Martin, 1997), and Verbal-Visual Strategies Questionnaire (Antonietti & Giorgetti, 1996). USOIMM77 was developed to assess the spontaneous occurrence of mental visualization in thinking; the Motor Imagery Questionnaire-Revised was developed to examine kinesthetic and visual movement imagery ability; the Verbal-Visual Strategies Questionnaire was developed to measure the cognitive disposition to use visual or verbal thinking strategies.

Two performances were recorded after each practice period to control for the variability in individual fluctuations that emerged in the pretest phase of the experiment, with some subjects performing better at the first recording due to short-term memory resources, and others at the second due to initial disorientation. The better performance of the two was selected for further evaluation. This selection was done according to the ratio score (see below) computed for both performances. The first recording was found to be the best in four subjects for MP, in three subjects for PP, in 8 subjects for MP+PP, and in 12 subjects for PP+PP.

Note-by-note recordings of the performances were acquired with a MIDI piano. Error detection analysis was done manually by the first author. Wrong notes were defined as any notes not corresponding to the prescribed note on the original score; an omitted note, as well as an undesired additional note was treated as a wrong note. MIDI data were used to compute two objective parameters of performance: 1) the absolute number of notes played and 2) the ratio between the number of wrong notes and the total number of notes played. The ratio score represents performance accuracy, scaled by the length of the performance. This allows discriminating between subjects who made a similar number of errors but played a different extent of the piece. For example, a subject who played 10 wrong notes out of 100 total notes would have a better (that is, lower) ratio score (ratio = 0.1), compared with another subject who made the same number of mistakes while playing only 50 notes of the piece (ratio = 0.2). DVD recordings of the performances were independently evaluated by three professional musicians (one pianist and piano teacher, one pianist, one professional flutist and amateur pianist). The professional experience of these evaluators ranged from 16 to 40 years in their fields. Raters were blind as to which practice condition preceded the recorded performances and were provided with the written scores. All performances were rated on four dimensions: 1) correctness of notes; 2) articulation and phrasing; 3) dynamics and expression; 4) global score. The first three features are typically examined during piano performance auditions and competitions, and have been used in past research on MP (Theiler & Lippman, 1995); an additional "global score" was collected to incorporate all aspects of music performance. Raters judged these dimensions on a Likert scale ranging from "1" ("poor") to "7" ("excellent"). For the "correctness of notes" dimension, raters were asked to take into consideration not only the correctness according to the score (already computed in the ratio), but also how well the notes, even wrong notes, fit the context. The "global score" dimension was independent of the quantity of music played. Recorded videos of the 30 min of MP (Phase 1-3) were used to quantify the time each subject spent in the following overt behaviors: 1) moving the fingers only; 2) singing only; 3) listening to the audio reproduction of the piece only; 4) moving the fingers while singing; 5) moving the fingers while listening to the audio track; 6) total time moving the fingers (even if other overt operations were going on); 7) total time singing (even if other overt operations were going on); and 8) total time listening to the audio track (even if other overt operations were going on). The time spent on these operations was expressed in seconds. This quantification was done by the first author.

STATISTICAL ANALYSES

Statistical analyses were run on SPSS 15.0. Normal distribution of the variables was assessed by means of the Kolmogorov-Smirnov test. In consideration of the small sample size, a conservative p value of .10, instead of .05, was assumed for this assessment. For each of the four dimensions of the rating, a measure of inter-rater reliability was obtained by averaging the Pearson correlation coefficient from each possible pair of raters, a method already used in past research on MP (Lim & Lippman, 1991; Theiler & Lippman, 1995). Separate repeated-measures analyses of variance (ANOVA) were conducted for each performance parameter, in order to evaluate differences in performance between MP, PP, MP+PP and PP+PP. Post hoc tests were computed using the Bonferroni correction for multiple comparisons. Partial eta squared (η^2_p) was assumed as a measure of effect size. Potential associations between individual features (initial questionnaires, imagery test) or strategic data (overt behavior, TMQ) and performance scores were assessed by the Pearson correlation coefficient. For the Pearson correlation coefficient, the .05 level of significance was assumed to be two-tailed for all variables, with the exception of the score on the musical auditory imagery test in relation to practice outcomes. The use of imagery during MP and PP was compared by means of two-sample dependent t-tests. Imagery during PP was compared with the theoretical "pure" absence of mental imagery by means of one-sample t-tests, with "1" as the test value; we therefore compared subjects' actual answers with the mean of an hypothetical group of subjects that successfully avoided mental imagery while doing PP ("1" = "not at all" answer on the TMQ). The validity of the TMQ was assessed in a one-sample t-test by comparing the scores obtained in the validation questionnaire with "3" as the test value. We therefore tested whether subjects' actual answers were significantly shifted toward the high values, compared with the mean of a hypothetical group of subjects that rated the questionnaire as just "intermediately" relevant and clear. Except for normal distribution, all analyses were evaluated at the .05 level of significance.

Results

The average level of agreement between the three raters was .79 for correctness of notes, .63 for articulation and phrasing, .58 for dynamics and expression, and .75 for global score. Compared with previous studies (Lim & Lippman, 1991; Theiler & Lippman, 1995), inter-rater reliability was considered high enough to warrant averaging the three raters' independent judgments for each performance. Each of the four dimensions of rating showed a high level of correlation with the others (average correlation for correctness of notes: $r = .84$; articulation and phrasing: $r = .84$; dynamics and expression: $r = .80$; global score: $r = .85$); these dimensions were therefore collapsed into a single "rating" indicator by summing up the score on each dimension for each subject (rating range: 4-28). This procedure was done to decrease the possibility for Type I error variable-wise, considering the relatively small sample size. All variables showed normal distribution, with the exception of the following MP strategies: formal analysis as reported in the preliminary questionnaire, and auditory imagery as reported in the preliminary questionnaire and in the TMQ. For these variables, the nonparametric Spearman's rho was used instead of the Pearson correlation coefficient. The two sonatas did not show differences in their degree of difficulty in any of the four

TABLE 1. Performance Scores for the Four Different Study Conditions.

Practice condition	Number of notes	Ratio wrong notes / total notes
MP	242 ± 110	.17 ± .17
PP	326 ± 101	.08 ± .11
MP+PP	319 ± 96	.07 ± .08
PP+PP	349 ± 86	.04 ± .04

Note: MP = mental practice; PP = physical practice.

conditions (MP, PP, MP+PP, PP+PP: $p > .05$ for number of notes, for ratio and for rating). The TMQ validation process provided support for its validity: Each of the seven items received a rating that was significantly better than "intermediate" for both clarity and relevance (one-sample t-test: all $p < .001$; all means > 3.87). The overall clarity and relevance of the questionnaire also received a satisfying evaluation, clarity: 4.86 ± .83; $t(37) = 31.74$, $p < .001$; relevance: 4.05 ± .94; $t(37) = 26.20$, $p < .001$. Concerning the musical auditory imagery test, it appeared to have a good internal consistency (Cronbach' alpha = .77). All items appeared to be worthy of retention: The greater increase in alpha would come from deleting item 1, but removal of this item would increase alpha only by .02. All items correlated with the total scale to a good degree (lower $r = .31$).

QUALITATIVE EVALUATION OF SUBJECTS' BACKGROUND

On the initial questionnaire, subjects most frequently reported the MP strategies of mentally hearing the sound of notes and using formal analysis (on average mentally hearing: 8.8 ± 1.9/10; formal analysis: 7.7 ± 2.1/10); visualizing movements was the least commonly used (on average 5.9 ± 2.9/10), mentally feeling movements and visualizing the score occupied an intermediate position (on average feeling movements: 6.9 ± 2.8/10; score visualization: 6.8 ± 2.9/10). Despite the high level of proficiency in piano playing and knowledge of MP skills, none of the subjects reported relying on MP as a major practice strategy.

MP

After 30 min of using MP, subjects were able to perform by memory on average 242 ± 110 notes (range: 112-387), corresponding to 63 ± 28% of the piece. The mean ratio (ratio wrong notes/total notes played) score was .17 ± .17 (range: 0 - .62). Mean scores for number of notes and ratio are reported in Table 1. Rating scores from the expert raters are reported in Figure 2.

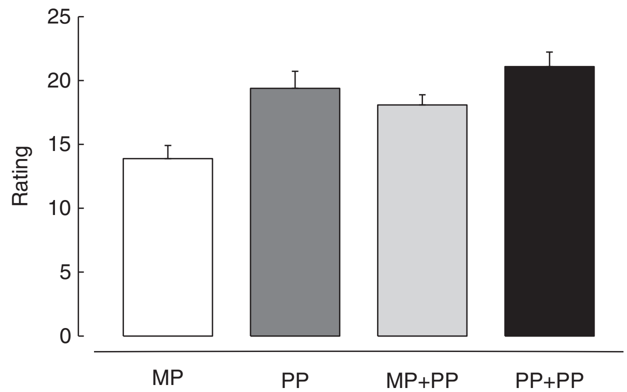

FIGURE 2. Expert raters' scores.
Note. MP = Mental practice; PP = Physical practice. Expert raters scored performance with reference to: i) correctness of notes, ii) articulation & phrasing, iii) dynamics & expression, iv) global evaluation. The four dimensions were collapsed into a single Rating indicator, shown in this figure. MP alone is significantly less effective compared with PP. However, with the addition of a short session of PP, MP resulted as effective as continued PP.

MP VS. PP

The analysis on the number of notes revealed significant main effects for the practice condition, $F(3, 12) = 11.51$, $p < .001$, $\eta^2_p = .43$, power = .99. Post hoc tests revealed that fewer notes were played after subjects used MP compared with the other conditions (PP: $p = .02$; MP+PP: $p = .03$; PP+PP: $p = .004$); no significant differences could be seen in the notes count between MP+PP and PP, or between MP+PP and PP+PP ($p > .05$). The analysis of the ratio also revealed a significant main effect for the practice condition, $F(3, 12) = 7.99$, $p < .001$, $\eta^2_p = .34$, power = .98. Post hoc tests showed a poorer (i.e., higher) ratio score for MP compared with PP ($p = .04$) and MP+PP ($p = .02$); a similar tendency could be observed for PP+PP also ($p = .056$), which did not reach statistical significance (possibly because of greater fluctuations in ratio scores after PP+PP, compared with the other conditions). No significant differences could be observed between the ratio values of MP+PP and PP, or between those of MP+PP and PP+PP ($p > .05$). Analysis of the ratings revealed significant main effects for the practice condition, $F(3, 12) = 26.21$, $p < .001$, $\eta^2_p = .64$, power = 1. Post hoc tests revealed lower ratings after the subjects' use of MP compared with all other conditions ($p < .001$). No significant differences emerged between PP and MP+PP ($p > .05$), while a qualitatively small but significant difference could be observed between MP+PP and PP+PP ($p = .02$). PP+PP scores on all three dimensions were possibly conditioned by a ceiling effect, given the nonsignificant differences between PP and PP+PP ($p > .05$).

TABLE 2. Mental Practice Strategies and Outcomes.

	Number of notes	Rating score	Ratio wrong notes /Total notes
Formal analysis (PRE-Q)		+	
Auditory imagery (PRE-Q)	+	+	
Auditory imagery (TMQ)	+	+	
Visual imagery – motor (TMQ)	–		
Auditory models (PRE-Q)			+
Auditory models (overt)		–	

Note: + indicates that a higher score on the item is related with a better post-MP performance; - indicates that a higher score on the item goes together with a worse post-MP performance. PRE-Q = Preliminary questionnaire; TMQ = Ten Minute Questionnaire, administered during mental practice; overt = overt behavior during mental practice, quantified from the video documentation.

MP: STRATEGIES AND OUTCOMES

The main association between MP strategies and post-MP outcomes are summarized in Table 2. In the next paragraphs, results will be displayed for each of the MP component we evaluated, following the order of the hypotheses we outlined in the Introduction.

FORMAL ANALYSIS

Stronger reliance on formal analysis for music memorization, as reported in the initial questionnaire, resulted in better post-MP rating score (Spearman's rho, two-tailed: $r = .77$, $p < .001$), and a similar tendency was observed for the number of notes also ($r = .47$, $p = .06$). Self-reports of harmonic, melodic, or rhythmic analysis during the 30 min of MP (TMQ data) did not show any association with post-MP performance during MP ($p > .05$).

AUDITORY IMAGERY

The score on the musical auditory imagery test was positively related to post-MP performance: Subjects with more developed aural skills were able to play more notes (Pearson correlation, one-tailed: $r = .45$, $p = .04$), had a better ratio score ($r = -.43$, $p = .048$), and got a higher rating score ($r = .45$, $p = .04$). Pitch imagery as a means to support music memorization, as reported in the initial questionnaire, was positively correlated with post-MP rating score (Spearman's rho, two-tailed: $r = .65$, $p = .007$) and number of notes ($r = .53$, $p = .033$), with a similar tendency for ratio ($r = -.48$, $p = .06$). Pitch imagery as a strategy reported during the 30 min of MP (TMQ data) was also correlated with a better rating score (Spearman's rho, two-tailed: $r = -.50$, $p = .049$) and greater number of notes played ($r = .51$, $p = .045$).

MOTOR IMAGERY

On the basis of the initial questionnaire and TMQ data, no associations could be detected between the strategy of motor imagery and performance scores.

VISUAL IMAGERY

Subjects who relied more often on movement visualization, as reported while using MP (TMQ data), gave a poorer post-MP performance according to the number of notes (Pearson correlation, two-tailed: $r = -.54$, $p = .03$). No interactions could be found between the score on the Motor Imagery Questionnaire-Revised "visual" subtest and the use of visual imagery of movements from the TMQ in predicting post-MP performance.

AUDITORY MODELS

The strategy of frequently listening to experts' performances, as reported in the initial questionnaire, was associated with a better ratio score (Pearson correlation, two-tailed: $r = -.64$, $p = .008$). On the contrary, time spent listening to the auditory model (without moving fingers or singing) during the 30 min of MP was associated with a poorer post-MP rating score ($r = -.58$, $p = .018$). Moreover, the subjects who reported in the initial questionnaire to rely on mentally hearing the sound of notes listened less to the audio recording during MP (Pearson correlation, two-tailed: $r = -.58$, $p = .018$).

OTHER OVERT BEHAVIORS

No associations could be detected between the time spent moving fingers or singing and performance outcomes ($p > .05$)

MENTAL IMAGERY DURING MP AND PP

Figure 3 shows the mean frequency of reliance on different mental strategies during practice. Consistent with the instructions given, subjects reported (TMQ data) having used MP strategies significantly less during PP compared with MP (MP vs. PP, dependent t-test for mentally hearing the sound of notes: $t = 16.35$, $p < .001$; mentally feeling movements: $t = 15.69$, $p < .001$; mentally visualizing movements: $t = 8.61$, $p < .001$; mentally visualizing the score: $t = 3.34$, $p = .001$;

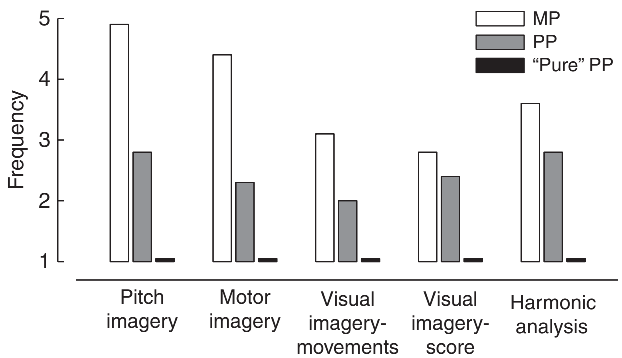

FIGURE 3. Mental strategies used during practice.
Note. Averaged reliance on different mental strategies in different practice condition, derived from averaged TMQ data. All mental strategies are used maximally during mental practice (MP). However, also physical practice (PP) is accompanied by imagery strategies, significantly more than one would expect in a hypothetical practicing condition with no use of imagery ("pure" PP).

harmonic analysis: $t = 3.52$, $p = .001$; melodic analysis: $t = 4.48$, $p < .001$; rhythmic analysis: $t = 5.73$, $p < .001$). Reliance on mental strategies was reduced in the PP condition also during the last 10 min of practice, when all subjects were allowed to physically play the instrument (MP+PP vs. PP+PP, mentally hearing the sound of notes: $t = 2.52$, $p = .017$; mentally feeling movements: $t = 5.80$, $p < .001$; mentally visualizing movements: $t = 2.35$, $p = .025$; harmonic analysis: $t = 2.81$, $p = .013$; rhythmic analysis: $t = 3.87$, $p = .002$). However, these findings also indicate that mental practice processes were always active during PP, although subjects were asked to avoid them and although they were trying to comply with this request. In fact, differences between the actual use of mental strategies during PP and the theoretical "pure" absence of these strategies (TMQ score = "1", "not at all") are constantly significant (one sample t-test for PP Phase 1-3: mentally hearing the sound of notes: $t = 6.13$; mentally feeling movements: $t = 5.14$; mentally visualizing movements: $t = 4.85$; mentally visualizing the score: $t = 6.14$; harmonic analysis: $t = 7.12$; melodic analysis: $t = 11.15$; rhythmic analysis: $t = 7.50$; all $p < .001$).

Discussion

A sample of pianists practiced to perform from memory two pieces of music of comparable length and difficulty. One piece was practiced by means of MP and the other by PP.

The comparison between post-MP and post-PP performances showed that MP alone allowed a level of proficiency between 40% and 60% of that achieved by PP. Moreover, combining an intense mental practice (30 min) with a relatively short physical practice session (10 min) led to results almost indistinguishable from those following 30 min of continued PP. These results are of immediate interest to musicians willing to: a) optimize the time available for practicing, b) have a deeper comprehension and stronger mental representation of the pieces they are practicing, or c) avoid massive physical practice and thus prevent playing-related disorders. All of these goals can be achieved by mental and physical practice properly combined, without a significant loss in terms of performance.

In a previous investigation involving behavioral and neurophysiologic recordings, MP alone resulted in significant learning, but did not result in as much performance improvement as PP alone (Pascual-Leone et al., 1995). In fact, at the end of five days of practice, the mental practice group's performance was at the same level as that of the group that had used PP for only three days. However, the plastic changes in the motor system following the use of MP alone were the same as those occurring by repeated PP; moreover, after a single PP session, the MP group's performance improved to the level of the group using PP for five days. As was suggested by Jackson (Jackson, Lafleur, Malouin, Richards, & Doyon, 2001), part of the behavioral improvement seen due to MP may be latent, and would thus become evident after the musician engaged in minimal physical practice. Mental practice could thus have a preparatory effect on the task, which increases the efficiency of subsequent physical training (Kopiez, 1990). With specific regard to music memorization, it is also interesting to look at the study on MP by Lim and Lippman (1991), which employed a rating system by expert judges very similar to the one presented in our study. The average ratings reported in Lim and Lippman's study closely matches those reported in our study, with subjects rating MP in the range of 3-4 on the 7-point Likert scale in both studies. Similarities also can be seen when comparing measurements of quantity of music that could be recalled after MP. Both ours and Highben and Palmer's (2004) study report that MP yielded 75% of the result following PP (however, the way music memorization is quantified in the two studies is not identical). We can therefore conclude that while present and past studies differed in terms of the degree of their ecological validity, they rendered a very similar picture considering the effectiveness of MP. Two explanations could account for this result. First, depending on subjects' aural skills and familiarity with MP, the lack of clear instructions on how to use MP may have led expert subjects to completely display their abilities, and hesitant subjects to get confused and misled. This could be particularly relevant when considering that none of our subjects reported systematically using MP while practicing, a detail that supports the training of subjects in MP before they are tested in experimental studies. Second, this result may be due to the fact that past studies also could not completely rule out the subjects' free use of MP, since the "undesired" cognitive operations implied in MP are unlikely to have been effectively switched off during the experiment. In fact, the TMQ data showed an aspect that has been partially neglected in previous research: PP intrinsically implies MP processes, despite the subjects' honest attempt to avoid them. From a cognitive point of view, MP appears to be an automatic rather than voluntary strategy used when facing a musical task. A musician can only partially regulate the degree of the ongoing MP, and in any case, it seems impossible to turn it off completely. In this respect, our data are in line with neurophysiological investigations showing automatic auditory-motor coactivation in musicians' brains during musical tasks (Bangert & Altenmüller, 2003; Haslinger et al., 2005). Thus, a dichotomy between MP and PP (or between different forms of MP), which in practical terms seems evident, appears to be rather arbitrary in terms of cognitive and neurophysiological processes. This has already been recognized by psychoneuromuscolar theorists, who have shown physiological activity in the form of electromyographic action potentials as a result of mental simulation of movements (Grouios, 1992; Hinshaw, 1991). Particular care to this ambiguity should be paid in the research context in which PP is often considered a control condition for MP and vice versa. Nevertheless, contrasting MP and PP still holds a practical significance for musicians. The proper experimental design of this contrast requires the scientist to be conscious of these tight links; "pure" PP, obtained by asking subjects to avoid mental imagery and rehearsal, appears to be an invalid control condition.

The present investigation has provided a novel contribution in understanding the relation between individual differences in practice strategies and practice outcome. In fact, the adoption of an ecologically valid perspective allowed for the first time to directly address the question, which strategies effectively support memorization in the absence of the physical instrument? Based on the assumptions of the expert memory theory (Ericsson & Kintsch, 1995) and its revision for the musical domain (Chaffin et al., 2009), we have put forward specific hypotheses for each component of MP that can now be discussed in light of the data.

Formal analysis as a MP strategy was expected to be associated with better performance. This was found to be true, but only to a certain degree. We found a significant association between the general habit of using formal analysis for music memorization, as reported in the initial questionnaire and performance results. This likely happens because building a formal structure of the piece allows the performer to use a retrieval, hierarchical scheme that results in a better organization of both practice and memory (Chaffin & Imreh, 1997). In this respect, formal analysis would facilitate the organization of the material to be remembered in chunks of information (Miller, 1956), that could be later recalled as units, thus optimizing the encoding and the retrieval of memories. The use of the formal structure of a piece to organize practice and aid memory is a standard recommendation of piano pedagogues (Leimer & Gieseking, 1998; Sandor, 1981); consistently, experts and advanced performers appear to utilize analytical strategies frequently, while inexperienced performers do not (Hallam, 1997; Williamon & Valentine, 2002). However, no direct associations could be found between the actual implementation of formal analysis during the experiment and performance outcomes. Three interrelated explanations can be proposed for this unexpected finding: First, particularly for experienced musicians, formal analysis may occur as a background, semi-unconscious process that actually shapes the way the pianist reads and practices music without necessarily becoming a deliberate and explicit tactic. As such, it is more likely to be consistently reported as a general attitude in an initial questionnaire as opposed to a TMQ-like formulation. Second, the time constraints we implemented could have further influenced the choice of practice strategies toward implicit formal analysis, so the subjects could spare the most time for directly practicing the retrieval from memory. It is possible that in a more relaxed setting, as the one described by Chaffin and Imreh (2002), different choices would have been reported. Third, at a conscious level, the use of formal analysis might have been obscured by the use of another, closely connected mental strategy: pitch imagery.

In fact, pitch imagery was expected to be a central element of effective MP. This hypothesis was confirmed by a tightly interconnected array of results, showing that better post-MP performance was achieved by subjects who a) had more developed aural skills, b) reported a general reliance on pitch imagery to aid music memorization, and c) reported the actual use of pitch imagery during the experiment. The other forms of mental simulation – motor and visual imagery – showed no association with effective performance (or even a negative relation in the case of mental visualization). These observations lead to the conclusion that effective memorization of a piece of music by mental practice requires the mental representation of how the music sounds. Indeed, it is most likely that this key information serves as raw material for building a higher-level, hierarchical representation such as the structural one. These empirical findings from a novel experimental setup substantiate practical teaching and pedagogical literature (e.g., Gordon, 1997; Leimer & Geiseking, 1998) as well as previous experimental results with a different methodological background (Highben & Palmer, 2004). The potential of pitch imagery in mental rehearsal can be also appreciated when considering how it has been shown to engage the brain. Neuroimaging studies have shown that neural activity within regions of the secondary auditory cortex can occur in the absence of sounds, and this likely mediates the phenomenological experience of imagining music (Zatorre, 2007).

Representations of how the music looks or feels seem more epiphenomenal, being more likely to distract than to empower music memorization. Future studies will determine whether a different set of strategies might be predictive of optimal performance for tasks with stronger emphasis on the motor, rather than on the cognitive aspects of piano playing (e.g., playing in a fast tempo, solving technical difficulties).

Turning to the role of external, auditory models, the literature we reviewed in the introduction has shown that external, transitional formats of representation are helpful to a certain extent (Theiler & Lippman, 1995). However, experts in a certain field tend not to use them (Hatano & Miyake, 1977). A very similar picture emerges from the present results: The habit of enriching internal representation by collecting, reviewing, and matching external enlightening models may have a long-term impact on the ability to reproduce such models on one's own. In this way, when faced with the situation, one can rely on already developed and stored representation, without wasting resources on external models that are likely to be more time consuming, less integrated with the other ongoing processes, and that possibly even conflict with one's own models (Lim & Lippman, 1991). We can hypothesize that the higher the level of internal auditory/structural representation, the less effective an auditory external model will be, and vice versa. Interestingly, while these considerations apply well to auditory models, they seem not to account for finger movements. No relation could be observed between the strategy of simulating piano playing on the table and practice outcomes. Even more surprisingly, continuously moving fingers was the strategy used by many of the more—as well as less—proficient subjects in our sample. For some, moving fingers seemed to lead to stable and reliable traces that physically shaped a robust structural comprehension of the piece; for other subjects, it seemed a blind, mechanical shortcut that produced a blurred and weak performance. These results may open a debate that may be answered more conclusively with a larger sample. In any case, the present results challenge the validity of studies that force subjects toward predetermined ways of mental practice.

Altogether, these findings have practical implications for the way musicians could rehearse or memorize new repertoire when the instrument is not available: First, imagery of the sounds should be a default operation, a foundation on which other operations rest. Second, analyzing the structure of the piece in terms of harmonic relations, melodic phrases, and rhythmic structures is another key component of effective MP. This applies to formal analysis not just as a deliberate, explicit operation, but also as a background process that runs parallel to the auditory/motor rehearsal. Third, reliance on external models can be an effective way to support practice, as long as it is clear that the goal is to build up an auditory/structural mental representation that holds even when the model is no longer present. Finally, motor and visual cues as well as overt finger tapping could be of occasional help, depending on the specific nature of the piece and the subject's preferences. However, they alone do not provide a reliable foundation for mental study, and in some cases they might even become a source of distraction.

Another question that prompted the present study was whether there are common MP profiles. From a qualitative overview of overt and covert practice strategies, mental practice for music memorization appeared to exist in two different forms. On the one hand, there was a mostly "mental" use of MP. Subjects who applied this type of MP were mainly focused on their internal processes, sometimes aiding their mental representations by listening to the auditory model. They showed almost no overt behavior, and they were focused on the abstract-formal analysis of the piece, without spending particular effort on the imagery of the precise movements. On the other hand, a more physical form of MP was observed. Subjects who applied this type of MP frequently supported their internal operations with overt behaviors such as moving fingers and/or singing, and balancing their internal operations between formal analysis and movement imagery. Interestingly, our data do not show an advantage of one category over the other, as the main discriminating factor between these groups—finger movements—was not associated with practice outcomes. Both kinds of patterns may lead per se to good or poor results, and probably each musician should find a personal, optimal balance between the two, also depending on the task.

While providing new insights into the mechanisms and possible applications of MP, this study presents the following limitations: a) The subjects' selection. Although all our subjects were familiar with MP, none relied on it as a major practice strategy; b) The small sample size. Results await to be confirmed by a larger sample; c) The task. To perform a novel piece of music by memory after a short practice session is not a very common task, as already noted by Theiler and Lippman (1995). This problem is likely to interact with our subjects' lack of expertise with MP, since even those who really had some MP skills probably never used them when faced with this kind of task; d) "Pure" PP as a control condition for MP. Although we were aware that inclusion of "pure" PP in our experimental design could have presented methodological problems, these problems had never been addressed or quantified in previous studies. The present investigation sought to demonstrate these problems and, thus, eliminate a source of ambiguity for future research. This intention, however, limits the ecological validity of our control condition, keeping a component of unnaturalness in our investigation.

Such limitations may interestingly guide the next steps for further research on MP. First, one could train subjects in MP prior to the study. The quantification of MP skills could be related in diaries for daily-use report as well as measured objectively (e.g., musical auditory imagery test, solfège, sight-reading, improvisation, ear-learning). A detailed entry file would allow researchers to keep even low-experienced subjects and to make separate analyses for subjects with different skill levels. Second, an exploratory, qualitative survey aimed to describe how and when musicians typically apply MP could precede a novel experiment employing more widely used tasks in an ecologically valid setting. Third, MP could be contrasted with "ecologically valid" PP (not assumed to exclude MP processes). Greater effort could be used to describe MP processes: TMQ reliability could be improved by randomizing the order of the item and reversing the scales to better disrupt memory for the previous rating assigned; think aloud procedures could also be considered. Finally, designs with free MP-PP combinations could be developed, giving, for example, percentage-time for each condition as the only constraint.

Developing research in these directions will be of great interest in both theoretical and applied frameworks. The results from the present, methodologically "open" study represent an encouraging step toward a deeper comprehension of the mechanisms by which memorization of complex tasks can be improved. No less important, conclusions from this line of research could have a direct impact on the possibility for musicians to better cope with health risk factors and to promote their own well-being.

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Appendix

TEN MINUTE QUESTIONNAIRE (TMQ)

The following statements describe strategies that a musician might use while using mental practice.

According to the way you practiced, rate each statement from 1 to 5 using the following scale:

1 = never
2 = seldom
3 = sometimes
4 = often
5 = very often

1. How often did you imagine the sound of notes?
2. How often did you imagine the feeling of the movement of your fingers or hand?
3. How often did you visualize in your mind the movement of your fingers or hand?
4. How often did you visualize in your mind the music score?
5. How often did you analyze the harmonic structure of the piece?
6. How often did you analyze the melodic structure of the piece?
7. How often did you analyze the rhythmic structure of the piece?

SUPPLEMENTARY FIGURE 1. Excerpt from Sonata K 72.

SUPPLEMENTARY FIGURE 2. Excerpt from Sonata K 113.