The Effects of Limited, Restricted Music Practice on Overnight Memory Enhancement

Sarah E. Allen¹ and Robert A. Duke²

Abstract
During evening practice sessions, 32 nonpianist musicians learned a short melody on piano, and then either learned a second short piano melody, learned a difficult unfamiliar piece on their principal instruments, practiced familiar material on their principal instruments, or engaged in no other music-related motor behavior prior to sleep; practice on the target melody was limited in terms of time and number of repetitions. All participants returned the next morning and were tested on their performance of the target piano melody. Previous research has revealed overnight enhancement of skills as a result of sleep. In the current study, however, our participants showed significant decrements in performance between evening training and morning test, though the extent of the decrements varied. We speculate that the lack of overnight improvements may have resulted from our regulating participants’ practice of the target melody during the training sessions and that strict, limited practice protocols may interfere with consolidation-based memory enhancement.

Keywords
memory consolidation, motor learning, motor skills, music learning, music practice, sleep

Highly skilled musicians typically spend many hours each day refining their performance skills and learning new repertoire, thoughtfully planning sequences of tasks that yield improvements in strength, facility, fluency, consistency, and speed (Ericsson, Krampe, & Tesch-Römer, 1993; Krampe & Ericsson, 1996). Repeated practice over time often improves these dimensions of music performance, but the changes in the brain leading to the mastery of refined skills are just beginning to be more clearly elucidated (Duke, Allen, Cash, & Simmons, 2009; Simmons & Duke, 2006).

Practice is such a central part of musical development that deciphering the underlying mechanisms that govern the formation and refinement of procedural memories, like the memories of music skills, contributes to teachers’ understanding of learning processes in music and will ultimately lead to more informed and intelligent pedagogy. Recent research in memory formation has revealed unexpected aspects of learning, perhaps most interesting, the refinement of memories absent active practice.

The positive effects of practice are typically observable within a given practice session, and musicians often gauge their productivity based on the extent of the changes they observe in the moment. Research conducted over the past two decades has shown that the refinement and enhancement of skills (i.e., further learning) may continue long after active practice has ended through the process of memory consolidation (Walker, 2005). This additional learning occurs absent the conscious attention of the learner, as evidenced by continued neural activation of the memories engaged during active practice and the subsequent changes in the physical configuration of those memories in the brain (Korman, Raz, Flash, & Karni, 2003; Walker, Brakefield, Seidman, et al., 2003).

It is now understood that during the hours following initial practice of novel skills, for example, newly formed procedural memories are stabilized, rendering them less susceptible to interference (distortions in memories that occur as a result of competing experiences) or forgetting (Brashers-Krug, Shadmehr, & Bizzi, 1996; Walker, Brakefield, Hobson, & Stickgold, 2003). During overnight sleep, memories encoded during the waking day undergo further modification and refinement, often resulting in observable enhancements in performance the following day (Brashers-Krug et al., 1996; Korman et al., 2003; Walker, Brakefield, Hobson, et al., 2003).

¹Southern Methodist University, Dallas, TX, USA
²The University of Texas at Austin, TX, USA

Corresponding Author:
Sarah E. Allen, Division of Music, Southern Methodist University, P.O. Box 750356, Dallas, TX 75275, USA.
Email: sarahallen@smu.edu
It has been demonstrated that learning two novel tasks in close succession may reduce or eliminate the overnight consolidation-based enhancements that would typically be observed in the performance of the task learned first (Brashers-Krug et al., 1996; Goedert & Willingham, 2002; Panzer, Wilde, & Shea, 2006; Walker, Brakefield, Hobson, et al., 2003), although the mechanism underlying this interference is not well understood. Walker, Brakefield, Seidman, et al. (2003), studying performance on a sequential keypress task, found significant improvements in participants’ performance of a single novel sequence following a night of sleep; however, when participants learned two sequences in a single training session, Walker et al. observed a decline in performance following sleep in the performance of the sequence learned first. To rule out the possibility that learning a second sequence had immediately interfered with the memory of the sequence learned first, another group of participants learned the same two sequences, but were tested on the first sequence immediately after learning the second (rather than after 24 hours). These participants showed no decrements in speed or accuracy at the end of training, indicating that the interference seen following a night of sleep had occurred during sleep-based consolidation, not during active practice of the second task.

Although the limited available data indicate that learning multiple tasks in juxtaposition may interfere with memory consolidation processes, the extent to which interference is affected by the degree of similarity between two tasks learned in close proximity is unknown. In most studies examining interference between procedural memories, participants have practiced two highly similar sequential keypress tasks (Cohen, Pascual-Leone, Press, & Robertson, 2005; Duke & Davis, 2006; Panzer et al., 2006; Walker, Brakefield, Hobson, et al., 2003). Brashers-Krug et al. (1996) simply changed the direction of the forces opposing participants’ movements on a reaching task. These studies have established that learning two similar, novel tasks in succession may interfere with the memory of the task learned first, but few researchers have examined variables related to task complexity and familiarity to the learner.

It is unclear whether practicing a familiar task, one that does not require the creation of a new cognitive representation (i.e., a new memory), might affect the consolidation of another novel task learned in close proximity. Balas, Roitenberg, Giladi, and Karni (2007) and Balas, Netser, Giladi, and Karni (2007) discovered that a familiar, complex task could interfere with a novel, simpler one, in the case of a sequence-tapping task and a familiar handwriting task. They offer that perhaps well-learned complex movements are recorded in memory as a collection of individual, simple components (i.e., parts of the complex movement), one or more of which may overlap memory traces of newly learned movements. This hypothesis, however, has not yet been examined in the domain of music.

Of course, musicians typically practice numerous familiar and unfamiliar movement sequences within a single practice session. In the current study, we examined the effects of practicing multiple skills in a single practice session on the overnight memory consolidation of a novel target skill. Five groups of participants practiced the same target keyboard melody during evening training sessions and were tested the following morning. Four of the groups, after practicing the target melody in the evening, then practiced one of four different tasks during the same session. A fifth group practiced only the target melody. We compared the extent to which the tasks practiced second during the training sessions affected the performance of the target melody following overnight sleep.

### Method

Participants were 32 right-handed undergraduate and graduate music majors enrolled in various degree programs in the Sarah and Ernest Butler School of Music at The University of Texas at Austin. All were woodwind or string players who had completed four semesters of undergraduate class piano instruction and had taken no more than 2 years of private piano instruction. All participants were financially compensated for their participation. The study met all applicable requirements of the institutional review board of The University of Texas at Austin.

All participants reported for two sessions approximately 12 hours apart, one in the evening and one the following morning. During the first session, participants practiced a 9-note melody with their nondominant hand on a Roland KR-4700 digital piano (Figure 1). After practicing the melody, participants in Group 1 learned a second 9-note piano melody (Figure 2), practicing in the same manner; participants in Group 2 practiced familiar material on their principal instrument; participants in Group 3 learned a novel melody on their principal instrument (Figure 3); and participants in Group 4 engaged in no other music-making prior to sleep.

![Figure 1. Target Piano Melody (performed by all groups).](image-url)
The practice of the target piano melody consisted of three blocks of 15 discrete performance trials each. Participants were instructed to perform the melody “as quickly and accurately as possible,” from beginning to end. Each trial began with an audible start signal, indicating they could begin the trial, and concluded with the participant’s 9th keypress. Following a 2-second delay, participants again heard the start signal indicating that they could begin their next trial. The three training blocks were separated by 30-second rest periods.

After participants completed the three training blocks on the target piano melody, participants in Group 1 then practiced the second piano melody following an identical protocol; participants in Groups 2 and 3 practiced either familiar or unfamiliar material on their principal instruments for 8 minutes (an amount of time approximately equal to the time spent on the target piano melody). Participants in Group 2 were instructed to practice on their principal instrument material (which they chose) that was familiar to them, such as warm-ups, scales, and exercises that were part of their daily practice routines. Participants in Group 3 were shown a novel, difficult piece that they then sight-read on their principal instrument (see Figure 3); they were told that they would have 8 minutes to practice after which they would be recorded performing the piece as quickly and accurately as possible.

Before participants began each morning and evening practice session, they rated their feelings of alertness using the Stanford Sleepiness Scale. Prior to beginning the study, participants agreed to refrain from drugs, alcohol, and caffeine for 12 hours prior to and during the experiment and to get a full night’s sleep between evening and morning testing sessions. Participants also agreed to refrain from performing any further fine motor skills with their fingers after the evening training sessions, such as typing on a computer keyboard or practicing on their instruments.

The following morning, all participants returned and were tested on the target (first) piano melody. The test session consisted of three blocks of 15 trials.

The MIDI data for the piano performances were recorded on an Apple laptop computer using a template for existing software (Max/MSP) written specifically for this experiment. We compared the accuracy (mean number of errors per sequence) and speed (mean duration per sequence) between the training and test sessions.

### Results

On our initial examination of the data, we determined that five participants performed at speeds that were greater than 2 standard deviations slower than the overall mean speeds for their groups. Given their extreme values, we did not include them in the analysis. The resulting group sizes were Group 1, n = 7; Group 2, n = 7; Group 3, n = 7; Group 4, n = 6.

We found no significant changes in performance accuracy between training and test, $F(1, 23) < 1$, $p = .738$, and there was no group by time point interaction, $F(3, 23) < 1$, $p = .871$; see Figure 4. Errors tended to be sporadic and infrequent, and it seemed participants in general sacrificed speed for accuracy; they were much more likely to play the melody more slowly than to play a wrong note, a way of approaching practice that seems common among experienced musicians.

All groups performed at similar speeds at the end of training, but the overall performance at test was significantly slower than the performance at the end of training, $F(1, 23) = 9.62$, $p = .005$, and the interaction between time point (end of training versus test) and group approached significance, $F(3, 23) = 9.62$, $p = .074$. All groups, including the control group, performed more slowly at test than they had at the end of training (Group 1 = 1,506 milliseconds (ms) at training, $SE = 145$; 1,538 ms at test, $SE = 107$; Group 2 = 1,468 ms at training, $SE = 121$; 1,717 ms at test, $SE = 94.5$; Group 3 = 1,578 ms at training, $SE = 52.9$; 1,687 ms at test, $SE = 78.2$; Group 4 = 1,451 at training, $SE = 140$; 1513 ms at test, $SE = 137$; see Figure 5), though the magnitude of these differences varied among groups.

Participants in the control condition (Group 4), who practiced only the target melody, saw the smallest decrement in performance speed at test (62 ms per sequence slower than at the end of training). The mean speeds for Group 1, who practiced both piano melodies at training, were nearly identical from the last block of training to the first block of test (32 ms); Group 3, who sight-read on their principal instruments, exhibited an even larger decrement in speed (109 ms); and Group 2, who practiced familiar material, exhibited the largest decrement in performance speed from the end of training to test (249 ms).

### Discussion

Our purpose in this study was to examine how the learning and consolidation of a novel melody may be affected by performing other music tasks during a single practice session. Of course, musicians at all levels...
of accomplishment, novices and experts alike, routinely practice multiple tasks (e.g., lines in a method book, exercises, etudes, repertoire) within single sessions. It has been demonstrated rather consistently that procedural memories, including music performance skills, are enhanced as a result of sleep-based consolidation (Allen, in press; Cash, 2009; Duke et al., 2009; Duke & Davis, 2006; Simmons, 2012; Simmons & Duke, 2006), yielding observable improvements in performance absent additional practice. But the extent to which practicing different tasks in juxtaposition influences the consolidation of music skill memories is just beginning to be investigated.

Our results in the current investigation were quite unexpected, and they raise important questions about the conditions under which consolidation-based enhancements in procedural memories, like those involved in music performance, may be obtained. The most striking departure from the results of our previous research in this area was the finding that participants who practiced only the target melody (Group 4) prior to overnight sleep failed to show evidence of offline gains at test. In fact, none of the groups performed faster or more accurately after sleep than they had at the end of training. Participants in the control condition exhibited the fastest performance of all the groups at test, but they showed no improvement in accuracy or speed following a night of sleep. This may be the most important, though unexpected, finding in our study.

One of the interesting aspects of conducting research of this type is dealing with results that reveal something other than what the research was designed to investigate. It is often the case that results that are unexpected lead to
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further questions that have the potential to clarify our understanding of complex phenomena. Although the results of this one experiment do not suggest prescriptions for teaching, they do indicate that the conditions under which learners practice skills may influence the extent to which the naturally occurring processes of memory consolidation and enhancement take place.

It is understandable that many teachers operate under the assumption that learning occurs while students are actively engaged in practice and that learning ends at the end of a practice session. But data collected over the past two decades, in particular, have revealed quite clearly that learning (i.e., the improvement of skills) may continue after the cessation of practice and that the experiences encountered during active practice influence the potential “offline” learning that follows.

Unlike many of the experimental protocols that have been employed in the study of consolidation, our procedure limited the number of repetitions of the melody, and we signaled the beginning of each trial, thus restricting learners’ flexibility in practice. We propose that our lack of improvements attributable to overnight memory consolidation is a result of these practice procedures. Instead of playing the melody continuously for 30-second blocks as in many previous motor skill consolidation studies (Duke & Davis, 2006; Simmons & Duke, 2006; Walker, Brakefield, Seidman, et al., 2003), participants in the current study practiced the melody for a controlled number of discrete trials. Although this difference may seem slight, it seems to have been sufficient to prevent or obscure offline performance gains typically seen following sleep.

The participants who practiced familiar material (Group 2) showed the greatest difference between training and test, performing the target melody more slowly during test than at the end of training. This was not expected, as the participants were trained musicians practicing highly rehearsed, and presumably highly automatized, behaviors on their own primary instruments. We had predicted that performing on principal instruments would create little interference with memories of the target melody because participants were calling on already existing memories and not creating a completely new memory that would require subsequent consolidation. It seems highly probable, however, that once an existing memory is recalled—on musicians’ principal instruments, in this instance—the information and experience gained during further practice, despite its familiarity, must then be integrated into the existing memory, requiring additional processing following practice. A recent study by Balas, Roitenberg, et al. (2007) supports this conjecture, as they demonstrated that performing a well-practiced task interfered with consolidation-based gains for a dissimilar, novel task. They suggest that complex but well-practiced routine movements have a higher potential to “overlap” with the neural representation of simpler ones, causing interference. This certainly seems to be applicable in the context of musicians practicing well-rehearsed music tasks.
The differences among groups at test were smaller by the end of the third (final) test block than at the beginning of the morning test, which suggests that whatever differences may have existed at the beginning of test were less apparent after further repetitions of the melody. Previous research has not yet examined the effects of extended music practice following overnight sleep, and it is impossible to infer from the data in this study whether initial decrements in performance at test persist over continued practice.

Our investigation illustrates that sleep-based enhancements in procedural memories may be dependent on practice procedures employed during training. This null result is an important finding. Multiple investigations have found enhancements in procedural memories following sleep, but our results show that the nature of practice may influence the extent to which consolidation-based gains are obtained. Investigators to date have used specific procedures for practice in demonstrations of performance gains attributable to overnight memory consolidation (Allen, in press; Cash, 2009; Duke et al., 2009; Duke & Davis, 2006; Simmons & Duke, 2006). Whether these gains are limited to specific practice procedures deserves much further scrutiny, as our current results demonstrate. Participants in the current study were restricted both in the timing and in the number of repetitions during practice. The practice procedures we employed could very well have obviated any observable effects on accuracy attributable to overnight consolidation and, further, resulted in no gains in performance speed.

The complex processes underlying music learning are just beginning to be more clearly understood; a deeper understanding of the fundamental processes of memory encoding, consolidation, integration, and retrieval will not only clarify the nature of developing procedural skills but may also inform our strategies for maximizing the effectiveness of music practice.

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