Effects of early break intervals on musicians’ and nonmusicians’ skill learning

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Abstract
We measured the extent to which motor skill performance is advantaged by break intervals that include varied types of cognitive activity interposed early in a training session, directly comparing the performances of musicians and nonmusicians. Participants (N = 118; 59 music majors, 59 nonmusicians) learned a 5-element keypress sequence on a digital piano during 12 min training sessions. Participants in three conditions took a 5 min break after 3 min of practice, and either practiced a new 5-element sequence (Break-motor), memorized word pairs (Break-word pair), or conversed with the proctor (Break-talk). Those in the fourth condition took no break (No-break). Participants were tested 12 hr later, following a night of sleep. Participants made significant performance gains across training and test, but musicians significantly outperformed nonmusicians at all timepoints. Nonmusicians made greater percentage gains than did musicians over the 5 min break interval and overnight, and participants in the Break-motor condition made significantly smaller gains over the 5 min break interval than did participants in the Break-talk and Break-word pair conditions. These results demonstrate that tasks involving declarative memories do not diminish performance enhancements that accrue during breaks early in motor skill practice, but these enhancements can be inhibited by engaging in competing motor tasks.

Keywords
motor skills, memory consolidation, music practice, performance, neuroscience

Motor skill learning is an experience-driven and time-dependent phenomenon central to the act of music practice. It is well understood that the repetitive nature of skill practice serves to

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engage neural processes that remain active even after practice ends, extending across subsequent intervals of wake and sleep. During these periods, memories for new procedural skills (e.g. tapping a sequence of keys on a computer keyboard) are stabilized through the process of memory consolidation, which involves structural and functional reorganization of neuronal representations of recent experiences. Consolidation transforms new, initially labile representations into long-term motor memories that are later retrievable, even after extended periods of time (Walker, 2005; Walker, Brakefield, Hobson, & Stickgold, 2003; Walker, Brakefield, Seidman, et al., 2003).

Based on the results of numerous investigations of procedural memory formation, Walker (2005) proposed that consolidation processes render these new procedural memories resistant to interference and forgetting over periods of waking (Walker & Stickgold, 2004) and subsequently modify them during intervals of sleep in ways that enhance performance when the memories are later retrieved (Fischer, Hallschmid, Elsner, & Born, 2002; Kuriyama, Stickgold, & Walker, 2004; Maquet, Schwartz, Passingham, & Frith, 2003; Mednick, Nakayama, & Stickgold, 2003; Vertes & Eastman, 2000; Walker, Brakefield, Hobson, et al., 2003; Walker, Brakefield, Seidman, et al., 2003). Most of the studies cited here tested these ideas by examining learners’ acquisition and recall of simple motor skills on which they had had no prior training (e.g. the motor sequence task, or MST, which requires learners to perform a 5-element keypress task on a computer keyboard).

The interpretation of these findings has been called into question by several authors (e.g. Nettersheim, Hallschmid, Born, & Diekelmann, 2015; Rickard, Cai, Rieth, Jones, & Ard, 2008; Rickard & Pan, 2017; Vertes, 2004) who assert that the protocols used in past studies to evaluate behavioral performance of the MST (used in numerous experiments that show sleep-based enhancements of performance) underestimate the extent of learning during training and post-training periods of wakefulness and thereby overestimate the extent of enhancement following sleep. Rickard and his colleagues have shown in multiple investigations that alternative analyses of performance that consider the differences in speed and accuracy within a 30 s practice block provide evidence of reactive inhibition or fatigue that, if not taken into account, lead to underestimations of the extent of learning achieved during active practice and thus overestimate performance gains observed following sleep.

Nettersheim et al. (2015) demonstrated that learners experienced a boost in performance 30 min after the cessation of active practice, but this performance enhancement decayed with the passage of time awake, with performance levels at 4 hr post-training returning to levels observed at the end of active practice. Following sleep, however, performance returned to the enhanced level demonstrated 30 min after practice. Thus, the results of Nettersheim et al. show that learners’ performance levels may increase in the absence of sleep and then return to training levels during wake, and that following sleep, this transient enhancement of performance is restored, becoming an expression of learning that persists over time.

It is important to recognize that the competing interpretations of the data reported above are not about whether memories undergo additional processing and modification following active practice, a phenomenon about which there is broad agreement. Rather, discrepant interpretations of the data concerning procedural memory consolidation focus on the neurophysiological mechanisms that lead to memory enhancement and the role of sleep in that process (for a recent review, see Poe, 2017; Sara, 2017). These discussions concern the extent to which procedural memories are enhanced offline (i.e. following active practice) and the contributions of sleep to this process.

These varied interpretations of performance raise questions related to identifying the unit of analysis that best represents what is learned in a given context, which is related to musicians’
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(i.e. musically trained adults) practice and to the measure that musicians typically use to assess whether something is in fact learned. Musicians typically monitor their own learning based on the sustained consistency of performance in context and over time. Few believe that their best iteration of a music passage is an accurate measure of its establishment in memory; rather, musicians gauge learning based on their ability to increase the frequency of better (e.g. faster, more accurate) repetitions of a music passage over extended periods of practice.

Investigations of experienced and naïve learners’ ability to acquire, encode, and retrieve memories for music and music-related skills, such as performing simple melodies, complex melodies, or short keypress sequences on a piano, have assessed the effects of post-training rest, including overnight sleep (Allen & Duke, 2013; Duke & Davis, 2006; Simmons & Duke, 2006; Tucker, Nguyen, & Stickgold, 2016; Van Hedger, Hogstrom, Palmer, & Nusbaum, 2015), the interposition of brief rest breaks during practice (Cash, 2009; Duke, Allen, Cash, & Simmons, 2009), practice of similar novel keyboard sequences and melodies in juxtaposition (Allen, 2012; Duke & Davis, 2006), distribution of music practice across varied intervals of time (Simmons, 2012), and the presentation of an auditory model prior to the start of music practice (Cash, Allen, Simmons, & Duke, 2014). Behavioral findings from these studies, which use data averaged over time, are consistent with much of the extant research regarding the mechanisms involved in the formation of procedural memories (Walker, 2005; Walker, Brakefield, Hobson, et al., 2003; Walker, Brakefield, Seidman, et al., 2003), but they also raise questions about the differences between unskilled learners and trained musicians, who have accumulated years of practice in learning and refining motor skills.

Of particular interest in the current study is the observation that the interposition of brief rest breaks during practice of a new skill often enhances performance, both during practice and following overnight sleep (Cash, 2009; Duke et al., 2009; Hotermans, Peigneux, Maertens de Noordhout, Moonen, & Maquet, 2006). The observation that rest breaks result in short-term boosts in performance was first reported over 100 years ago (Ballard, 1913; Denny, 1951; Eysenck & Frith, 1977; Holland, 1963). This phenomenon, termed reminiscence, has been observed following rest intervals ranging anywhere from seconds to minutes, but in nearly all instances performance returns to pre-rest levels as practice resumes following rest.

More recently, the more long-term effects of brief rest periods on initial skill acquisition have been shown to vary, depending on when breaks occur within a practice session. Cash (2009) compared the effects of rest intervals inserted in the early (following 3 min of practice) and late (following 9 min of practice) stages of 12 min practice sessions, and found that the extent of performance enhancement immediately following the breaks was similar, irrespective of when the break occurred. The most interesting finding in Cash’s study was that performance following the early break interval did not diminish following the initial boost when practice resumed, but continued to improve until the end of practice. In addition, Cash found that, compared to the later break and compared to practice without a break, the early break resulted in greater overnight gains, suggesting that the benefits of rest periods early in practice may extend beyond the initial practice session, and that learners who reach a higher level of skill earlier in practice—affording more repetitions at elevated levels before practice ends—may experience greater offline gains as well. This same effect has been observed among musicians learning a novel melody (Duke et al., 2009), although the magnitude of improvements both within and between sessions was somewhat smaller among musicians learning a melody than was observed among Cash’s nonmusician participants who learned a simpler, 5-element keypress sequence.

The observation that interposing early break intervals during practice of a motor task resulted in sustained performance gains during practice and increased improvements
overnight (Cash, 2009; Duke et al., 2009) inspired us to investigate whether engaging in declarative and procedural memory tasks during an early break interval differentially affects the expression of offline gains in the performance of a novel, simple motor task. We tested whether we could inhibit expected performance enhancements following an early break interval by having participants engage in a second, similar novel motor task. We compared this to other break conditions that did not involve motor activity, and instead focused on the formation and recall of declarative memories. In addition, no study to date has compared the performances of highly trained musicians (music majors) and nonmusicians learning the same motor sequence task in order to determine whether intensive music training advantages motor skill learning in contexts not directly related to musicians’ individual area of study. We also examined whether musicians’ and nonmusicians’ performance would be similarly affected by these break conditions.

Method

Participants

Participants were 118 university students (59 musicians and 59 nonmusicians) enrolled at Texas State University, Texas Tech University, and The University of Texas at Austin. Musicians comprised wind and string players, vocalists, and percussionists. All were music majors (non-pianists) who had accumulated years of intensive music performance study (see Table 1) and who had completed 1–4 semesters of undergraduate class instruction in piano. Nonmusicians reported that they had received fewer than three years of formal instruction on a musical instrument and had not participated in any substantial music making activities during the five years prior to the experiment. All participants were right-handed and reported having had no more than three years of piano lessons at any time during their lives.

Participants agreed to maintain what for each participant was a typical sleep schedule for two consecutive nights (the nights prior to and following the training period). Participants also agreed to abstain from drinking alcohol, using mind-altering drugs, or altering their typical consumption of caffeine for 24 hr (starting 12 hr prior to beginning the study). Participants gave informed consent and were financially compensated for their participation. All procedures were approved by the university institutional review board for human subjects research.

Procedure

Participants learned a 5-element keypress sequence on a full-size digital keyboard with fully weighted keys in individual sessions scheduled between 8:00 p.m. and 10:00 p.m. The 20 min training sessions comprised 12 30 s practice blocks separated by 30 s rest intervals. Participants learned the target sequence 2-5-3-4-2 using their non-dominant (left) hand and with the keyboard’s sound turned off (traditional left-hand piano fingerings: 2-index, 3-middle, 4-ring, 5-little finger—with fingers placed on keys F3, G3, A3, and B3). Participants were instructed to play the sequence as quickly and accurately as possible, repeatedly and without pause throughout each practice block. The finger numbers of the sequence were displayed on a computer screen positioned at the level of the keyboard’s music rack and were visible to the participants at all times throughout the experiment. This protocol is similar to that used in previous investigations of motor sequence learning in music (Cash, 2009; Duke & Davis, 2006) and non-music
Table 1. Participant Demographic, Experience, and Sleep Data by Group and Condition.

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Note. Counts, means, and standard deviations (in parentheses) for musician and nonmusician participants in each group.

1Number of participants in each group whose principal instrument involved the use of fingers of the left hand. 2Years of study on the principal instrument or voice. 3Number of participants in each group who had ever studied piano privately. 4Number of years of private piano study. 5Number of semesters of class piano instruction. 6Ratings of wakefulness using the Stanford Sleepiness Scale (SSS).

settings (e.g. Hotermans et al., 2006; Kuriyama et al., 2004; Walker, Brakefield, Hobson, et al., 2003; Walker, Brakefield, Seidman, et al., 2003).

We created four practice conditions that were assigned randomly to participants. In three of the four conditions, 5 min break intervals were placed after the third minute of the 12 min practice session (i.e. after three 30 s practice blocks); the fourth condition did not include a 5 min break (No-break). Breaks comprised one of the following activities: (1) practicing a new 5-element sequence (Break-motor), (2) memorizing a series of word-pairs (Break-word pair), or (3) conversing with the proctor (Break-talk). The proctor initiated conversations, posing questions that required the recall of episodic memories (e.g. “Describe how you came to campus today”). This type of verbal engagement between the participants and proctors took place during all break intervals—the 30 s intervals between practice blocks and the 5 min break intervals.

All participants returned the following morning, approximately 12 hr after training, for a test session consisting of three blocks of practice separated by 30 s rest intervals. At the beginning of each session, participants reported whether they had complied with the instructions regarding sleep, alcohol, caffeine, and other drugs, reported their hours slept, and completed a brief measure of wakefulness via the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Philips, & Dement, 1973).
Materials
Musical Instrument Digital Interface (MIDI) data for all training and test performances were recorded using a Max/MSP software patch written specifically for experiments of this type. Performance was measured in terms of the number of correct keypresses in each 30 s block (CKP/B), which takes into account both performance speed and accuracy. As in prior studies, performance in practice blocks was averaged across block triplets for analysis (Blocks 1-3, 4-6, 7-9, and 10-12 of training, and Blocks 1-3 of test—see Cash [2009]; Duke et al. [2009]).

Results
To evaluate the possible effects of various aspects of musicians’ previous experiences on their performance of this task, we examined the effects of years of study on the principal instrument, whether the principal instrument involved use of the individual fingers of the left hand, years of private piano lessons (recall that no musician participant had studied piano privately at any time for more than three years), and the number of semesters of class piano completed (see Table 1). We found no significant relationships between any of these variables and participants’ performance on the first block of training, on the first block triplet (before the break intervals), or on any of the three gains scores that we examined in this experiment.

We analyzed reports of sleep and sleepiness ratings at training and at test in two-way analyses of variance (ANOVAs, Group by Practice Condition). We found no significant differences between musicians and nonmusicians or among practice conditions in terms of either hours slept prior to training ($p > .24$), hours slept prior to test ($p > .16$), Stanford Sleepiness rating prior to training ($p > .72$), or Stanford Sleepiness rating prior to test ($p > .32$). As expected, Stanford Sleepiness ratings were significantly correlated with reported hours slept prior to training ($r = -.27$, $p < .0001$) and prior to test ($r = -.26$, $p < .0001$).

In terms of motor performance, there were no significant differences among the four practice conditions at the beginning of training; we examined the CKP/B means for both Block 1 alone ($p > .33$) and the Block 1-3 triplet mean ($p > .12$). Musicians, however, significantly outperformed nonmusicians in both Block 1 ($F(1, 110) = 41.35$, $p < .0001$, $\eta^2 = .264$) and in the Block 1-3 triplet ($F(1, 110) = 48.54$, $p < .0001$, $\eta^2 = .291$). Musicians’ large performance advantage over nonmusicians persisted throughout training and test.

Given the large differences in CKP/B between musicians and nonmusicians, we conducted all further comparisons in terms of percentage gains. Specifically, we examined the percentage improvements overall, over the break interval (between the first and second block triplets), and overnight in separate two-way ANOVAs.

Nonmusicians made greater improvements than musicians in terms of overall percentage gains (from the beginning of training to test: $F(1, 110) = 8.26$, $p < .0001$, $\eta^2 = .066$—see Figure 1), but there were no significant differences among practice conditions in overall percentage gains ($F(3, 110) = 1.30$, $p = .279$—see Figure 2), and no interaction between group and practice condition ($F(3, 110) = 1.02$, $p = .386$).

Nonmusicians made greater improvements than musicians did in terms of percentage gains between the first and second block triplets ($F(1, 110) = 4.70$, $p = .032$, $\eta^2 = .026$—see Figure 1). There was also a significant effect of practice condition on percentage gain between the first and second block triplets ($F(3, 110) = 2.80$, $p = .04$, $\eta^2 = .065$—see Figure 2). Tukey’s HSD pairwise comparisons among percentage gains over the 5 min break revealed that the Break-motor condition gains were significantly lower than those of the Break-talk ($p = .046$) and the
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Break-word pair conditions ($p = .013$). No other differences between practice conditions were observed, and there was no interaction between group and practice condition ($p > .11$).

In the analysis of overnight percentage gains, nonmusicians again showed greater improvement than musicians ($F(1, 110) = 9.96, p = .002, \eta^2 = .080$—see Figure 1). Practice condition
Figure 2. Top: Mean CKP/B, averaged across 3-block triplets in training and test sessions, by condition. Grayed portion of the lines represents the break interval between Training 1-2-3 and Training 4-5-6, and the overnight interval between Training 10-11-12 and Test 1-2-3. Bottom: Percentage change between consecutive 3-block triplets. Error bars represent ±1 standard error.
had no significant effect on overnight percentage gains, however ($F(3, 110) < 1, p = .542$), and there was no significant interaction between group and practice condition ($p > .38$).

**Discussion**

This is the first study to examine advanced musicians’ learning of a simple motor sequence and the first to directly compare the performance of advanced musicians and nonmusicians. Even from the onset of practice, musicians clearly outperformed nonmusicians, suggesting that years of music training, albeit in voice or on instruments other than piano, advantaged musicians’ learning in this context. All of the musicians involved in this study had some form of fine motor skill training (e.g. years of oboe practice, multiple enrollments in group piano classes) that prepared their motor system to respond to the demands of this simple motor task with relative ease.

Comparisons of the performance changes that occurred across breaks (5 min break interval during practice, 12 hr post-training interval that included sleep) also revealed differences between musicians and nonmusicians. Nonmusicians showed a greater percentage gain following both the 5 min break and the overnight break than did musicians (see Figure 1). Considering that musicians’ performance was much better than nonmusicians’ performance to begin with, it is reasonable to assume that musicians would be less likely to demonstrate the same extent of percentage gain as nonmusicians.

Even so, there are notable differences in the shape of the learning curves shown in Figure 1 that warrant attention. After the large initial gains evident between the first two block triplets, the rate of musicians’ gains remained relatively consistent through out the remainder of practice and the test session whereas nonmusicians’ gains slowed during practice, but increased significantly following the overnight break. Perhaps musicians’ ability to persist in the sustained practice of fine motor skills related to music performance rendered them somewhat resistant to the effects of both mental and physical fatigue associated with massed practice (as described by Rickard et al., 2008), allowing them to continue making relatively consistent gains across time. Nonmusicians, who began their performance with a significantly lower rate of correct keypresses per block (CKP/B) than musicians and whose gains had slowed by the end of practice, seem to have benefited more from the combination of task repetition and subsequent time away from the target task.

It is important to note that our results are in some ways consistent and in other ways inconsistent with those of Tucker et al. (2016), who reported that undergraduate students who played musical instruments (but were not music majors) demonstrated superior performance on a similar motor sequence task relative to undergraduates who reported having no musical instrument experience. In contrast to our results, however, Tucker et al.’s music group demonstrated greater gains across training and overnight than did the non-music group. Unfortunately, Tucker and colleagues did not report data related to the nature of music training those identified as “musicians” had accumulated, but it is likely that their participants had much less experience and lower levels of music skill than did the music majors who participated in the current investigation. The idea that intensive music training may mediate the short- and long-term expression of performance improvements in this context is consistent with previous observations of smaller offline gains among musicians performing musical tasks (Cash et al., 2014; Duke et al., 2009) than are typically observed among nonmusicians performing 5-element keypress sequences (Cash, 2009; Duke & Davis, 2006; Tucker et al., 2016; Van Hedger, Hogstrom et al., 2015).

Musicians in this study also showed smaller overnight gains than did other musicians in previous studies using a more complex motor sequence task (Allen, 2012; Cash et al., 2014; Duke et al., 2009). This result is consistent with previous research (Debarnot, Castellani, &
Guillot, 2012; Kuriyama et al., 2004) showing that overnight enhancements are related to task difficulty, with greater gains evident in skills of greater complexity. Of course, the difficulty of a given task is a function of both the demands of the task itself and the skill level of the learner. The task in the present study was clearly easier for musicians than for nonmusicians.

It seems unlikely that musicians in this study experienced any kind of ceiling effect, as their performance continued to improve across training and test (see Figure 1). However, in this study, musicians performed with greater mean correct keypresses (CKP/B) throughout training and test as compared with previous reports (Allen, 2012; Cash et al., 2014), although it is important to note that in the studies of Allen and Cash et al., musicians learned a more complex target task (a 13-note melody) and, unlike in this study, could hear the sound of the keyboard while they performed. In contrast, the nonmusicians observed here performed similarly across training and test to other novice learners studied in extant literature (Cash, 2009; Duke & Davis, 2006).

It is important to note that, other than the differences we observed between music major and non-major participants, the effect sizes for the significant differences among break conditions were quite small. Our results suggest that the preliminary memory processing of a simple motor sequence during an early break is not adversely affected by other cognitive activities unrelated to motor performance (i.e. tasks engaging declarative memory). The percentage gain over the break among participants in the Break-word pair condition (who completed a word-pair memorization task during the 5 min break interval) was similar to that observed in participants who recalled episodic memories during the break (Break-talk; see Figure 2). Participants in the Break-motor condition, who learned a second, competing motor sequence, had a significantly lower percentage gain following the break interval than did the Break-word pair and Break-talk groups. Note again, however, the small effect sizes and the fact that none of the over-break gains in the three break groups were significantly different than the gains of the No-break group.

Our findings are in line with previous research indicating that procedural memory consolidation may be disrupted by learning a second, competing motor task before stabilization of a first-learned task is complete (Allen, 2014; Balas, Roitenberg, Giladi, & Karni, 2007; Duke & Davis, 2006; Walker, 2003). Our results indicate that, unlike learning competing motor tasks, engaging in declarative, non-motor activities does not interfere with the early stages of procedural memory formation.

Learners in the Break-motor group likely experienced the most fatigue during active practice, as they engaged in additional motor performance relative to the other groups. However, the observation that the Break-motor group made gains between the first and second block triplets similar to those of the No-break group, and the fact that their percentage gains across the remainder of training and test were not statistically different from any of the other groups, suggest that the Break-motor group’s performance was not substantially disadvantaged by fatigue.

Cash reported in 2009 that nonmusicians, learning the same task and with a break identical to the Break-talk condition in the present investigation, performed best across training and improved more overnight (in terms of mean correct keypresses) than did participants who took no break during training. This same trend was reported for musicians learning a more demanding keyboard melody (Duke et al., 2009). The present investigation fails to replicate these earlier findings. The idea that early breaks during practice may lead not only to short-term boosts in performance, but also to long-term gains is an important finding that may influence the ways that musicians and other learners may organize practice time. However, our lack of finding positive long-term gains in the present investigation raises questions about the robustness of this result.
Conclusion

Consistent with results of previous studies, musicians’ experience seems to change the time course and perhaps the extent of memory consolidation enhancement typically demonstrated by learners who have no training in fine motor skill performance. These data suggest that musicians’ training on primary and secondary instruments advantages their performance of novel, simple motor skills.

It is important to keep in mind that the over-break and overnight gains observed in this study, like those reported previously, occur absent further physical practice and without learners’ conscious attention. Discovering how time away from practice supports memory formation, even in the earliest stages of learning, may lead to practices that increase the efficiency with which learners acquire and perform simple and complex motor skills. Memory consolidation processes, as related to the various dimensions of music learning, remain somewhat obscure, but there are compelling findings that invite further investigation. Many questions remain about the role musicians’ experience plays in the encoding, storage, and retrieval of new skill memories, and in the identification of neural systems that operate during unique phases of memory consolidation.

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