Music Performance Research

Vol 2: 1-25
ISSN 1755-9219

Insights about practice from the perspective of motor learning: a review

Gabriele Wulf and Adina Mornell

ABSTRACT In this article, we review recent research in motor learning and discuss its implications for music pedagogy. Specifically, we review factors that have been shown to have reliable effects on motor learning, including augmented feedback, the order of tasks (blocked versus random practice), observational practice, the learner's focus of attention, and self-controlled practice. The findings suggest that the effectiveness of practice in music may be enhanced if feedback is given sparingly, variable task orders and observational practice are incorporated, instructions and feedback are used to induce an external focus of attention, and practice conditions allow for self-control.

KEY WORDS: Feedback, contextual interference, observation, attention, self-control, music education

While the learning of motor skills, including sport skills, has been examined in the laboratory, and countless empirical studies have been conducted to examine how factors such as feedback or the performer's attentional focus affect learning, musicians have chosen to look the other way. Instrumentalists and vocalists do not deny that virtuosic playing is a complex motor skill, but they shudder at the thought that their art can be analyzed and quantified. It is hard for them to relinquish the age-old belief that "hard science" cannot be used to fathom musical performance. Even music educators have shunned a systematic approach to teaching methods, preferring to rely on habit, instinct, and the master-student model that has been perpetuated for centuries (Richter, 2001). Indeed, music pedagogy has been consistently resistant to change, even in light of neurobiological evidence that has revolutionized scientists' understanding of learning and behaviour. Perhaps it is a question of identity: music teachers prefer to view themselves as artist-teachers rather than professional trainers. Fortunately, a new generation of musicians is developing curiosity for the work of experimental psychologists. In return, researchers in the field of motor learning are anxious to begin interdisciplinary studies, and welcome such adventurers with open arms, appreciative of participants who display prowess at some of the most complicated motor patterns humans can acquire.

This paper reviews research related to various factors, or practice conditions, that have been shown to have an impact on motor learning. Motor learning is typically defined as a *relatively permanent* change in the capability to produce motor skills (e.g., Schmidt & Lee, 2005). It is therefore important to keep in mind that certain practice conditions may have temporary or transient effects on performance (e.g., due to increased fatigue or enhanced motivation) that do not necessarily reflect more permanent, or learning, effects. Learning studies therefore typically consist of two phases: a practice phase in which participants practise under different experimental conditions, and delayed retention or transfer tests that are performed under common conditions for all participants. Those tests allow a cleaner assessment of what was learned, uncontaminated by the temporary influences associated with the experimental manipulations.

The learning variables we review in this paper include augmented feedback, the practice order of different tasks (blocked versus random practice), observational practice, the performer's focus of attention, and self-controlled practice. For each of these variables, we review experimental findings and address the implications of this research for musicians and music teachers. We hope that this review will stimulate further research in the field of instrumental pedagogy. It is our contention that such investigations would shed light on some of the unsolved questions posed by the evidence discussed in the following. Once a comprehensive understanding of music learning is applied to teaching methods, a tangible "science of practice" will emerge to replace the myths that surround the acquisition of musical skills.

Feedback

The typical scenario in music lessons is that of individual instruction, dominated by the teacher's critique of the student's performance through use of verbal feedback. Recent criticism of this model has arisen within the field of music education (some alternatives can be found in Ernst, 1991). Aside from the psychological and emotional problems associated with error correction – feedback may be perceived as negative, and the focus is on the judgment of others instead of one's own assessment, just to name two examples – instructor-provided feedback may interfere with the student's ability to process his or her own intrinsic feedback.

Research related to the effects of augmented feedback – that is, feedback that is given in addition to the individual's own intrinsic feedback – has a long history (for reviews, see Salmoni, Schmidt, & Walter, 1984; Schmidt, 1991; Swinnen, 1996; Wulf & Shea, 2004). The results of early feedback studies led researchers to believe that learning did not occur without feedback, and practice without feedback was thought to weaken the representation of movement in memory (e.g., Bilodeau & Bilodeau, 1958). Learning was assumed to be optimized when feedback was provided frequently and immediately (Adams, 1971; Schmidt, 1975; Thorndike, 1927). However, many of the early studies inferred learning from performance during practice and did not include retention or transfer tests (Salmoni et al., 1984). Those tests are now standard in feedback studies, and the findings of those studies have largely refuted earlier assumptions regarding the role of feedback.

In this section, we review newer findings related to the influence the *frequency* and *timing* of feedback have on learning. (Effects of the attentional focus induced by feedback and feedback controlled by the learner are reviewed in the sections on attentional focus and self-controlled practice, respectively.)

Experimental Findings

Feedback frequency. In the first study that examined the effects of feedback frequency on learning by using a delayed retention test, Winstein and Schmidt (1990) had participants learn to move a horizontal lever in a certain spatio-temporal pattern. Feedback, consisting of the goal pattern superimposed on the produced movement pattern, was provided after either 100% or 50% of the practice trials. The results showed that the 50% feedback group produced significantly smaller errors than the 100% group in retention. Thus, in contrast to earlier assumptions, the reduced feedback frequency actually enhanced learning. In several studies, different movement variations with the same relative-timing pattern (or rhythm), but different absolute-timing characteristics, had to be learned. In those cases, the learning of the relative-timing structure was clearly enhanced by a reduced feedback frequency, compared to 100% feedback (e.g., Lai & Shea, 1998; Wulf, Lee, & Schmidt, 1994; Wulf & Schmidt, 1989; Wulf, Schmidt, & Deubel, 1993). For example, in one study (Wulf et al., 1994) participants were asked to produce a 4-key sequence on a computer keyboard (i.e., 2-4-8-6 keys on the numeric key pad). While the overall goal movement times for three different task versions were different, the relative-timing structure of the three movement segments (between key presses) was identical (1 : 2 : 1.5) for all three task versions (200-400-300, 250-500-375, 300-600-450 milliseconds). For musicians, this is comparable to playing the same four-note rhythmic motif in three different tempos. The results indicated that learning of the relative-timing pattern was enhanced for participants who were provided feedback on 50% of the trials, as compared to those who received feedback on 100% of the trials. As can be seen in Figure 1, the 50% feedback group outperformed the 100% feedback group on both no-feedback retention (involving the 3 three practice task versions) and transfer tests (with novel absolute times: 350-700-525 milliseconds). Thus, the learning of the relative-timing structure was clearly enhanced by providing less feedback. (In contrast, learning of the absolute or overall duration does not seem to be hampered by frequent feedback.)

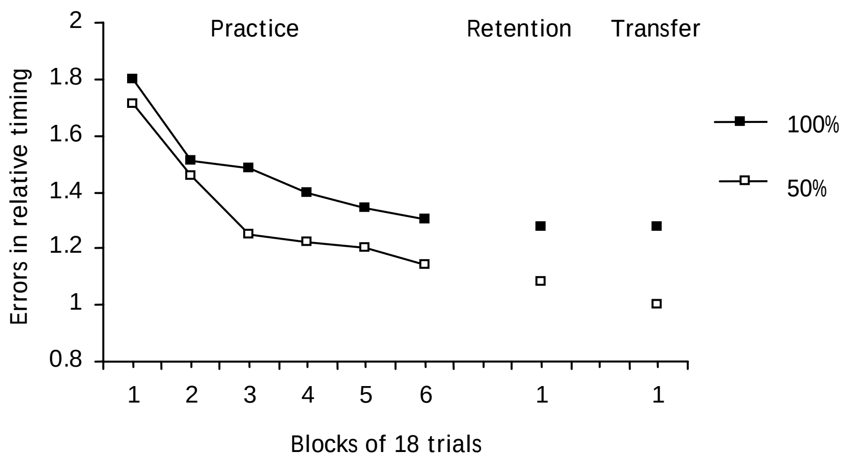

Figure 1. Relative-timing errors (sum of proportional errors on the 3 task segments) of groups receiving feedback on 50% or 100% of the practice trials in the study by Wulf, Lee, and Schmidt (1994).

Timing of feedback. Feedback is typically given after the completion of a movement. Yet, it can also be provided simultaneously with the movement ("concurrent" feedback). While it is often assumed that feedback given concurrently with the movement is effective, this is generally not the case. In fact, concurrent feedback is typically detrimental to learning, compared to feedback provided after the movement. For example, in some studies feedback, in which the task required participants to move a lever in a spatially and temporally defined pattern, the feedback consisted of the (position-time) curve produced by the lever movements being superimposed on the goal, or criterion, curve. Essentially, learners were able to observe their curve being "drawn" on the criterion curve while they were executing the movement. Even though concurrent feedback enhanced performance when it was present, clear performance decrements were seen when it was withdrawn in retention or transfer tests (e.g., Park, Shea, & Wright, 2000; Schmidt & Wulf, 1997; Vander Linden, Cauraugh, & Greene, 1993; Winstein, Pohl, Cardinale, Green, Scholtz, & Waters 1996). Thus, although feedback provided concurrently with the movement temporarily enhances performance, it has little or no long-term effect. This is frequently seen in musical instruction: as long as the teacher guides the instrumentalist through concurrent feedback (singing along, counting out loud, clapping, conducting in the student's field of vision), the student stays in rhythm. This "success" is however just a short-term performance effect, and not a sign of learning. This practice session within the lesson does not necessarily guarantee that the student will practise with this rhythmic stability, nor that he or she will achieve a more rhythmic performance at a later date.

It has also been found that giving feedback immediately after the movement is less effective for learning than delaying it for a few seconds (e.g., Swinnen, Schmidt, Nicholson, & Shapiro, 1990). This effect has been attributed to learners' spontaneously evaluating the movement – based on the processing of their intrinsic feedback – before the augmented feedback is presented. Specifically requiring learners to estimate their errors after the completion of a movement has been shown to enhance learning even further (e.g., Hogan & Yanowitz, 1978; Liu & Wrisberg, 1997; Swinnen et al., 1990).

Explanations for the Effects of Feedback Frequency and Timing

The effects of feedback frequency and timing have been interpreted in terms of the "guidance hypothesis" (e.g., Salmoni et al., 1984; Schmidt, 1991). This hypothesis received its name from the fact that feedback is assumed to guide the learner to the correct movement. But, according to this view, feedback also has negative effects. When it is provided too frequently, learners tend to become dependent on it, as they by-pass the processing of their own, intrinsic feedback. This effect is particularly pronounced when feedback is provided concurrently with the movement or immediately afterwards. As a consequence, learners fail to develop their own error-detection-and-correction mechanisms that would allow them to perform effectively when the augmented feedback is withdrawn.

Furthermore, frequent feedback during practice increases performance variability during practice, as individuals have a tendency to attempt to correct even small errors that may simply represent variability in the motor system (e.g., Schmidt, 1991). In contrast, interspersed trials without feedback prompt the learner to repeat the last trial – providing response stability that seems to be a prerequisite for the development of a stable movement representation.

It should be mentioned, however, that the effects of feedback frequency seem to depend, to a certain extent, on the complexity of the skill (see Wulf & Shea, 2002, 2004, for reviews). Whereas the learning of simple skills typically benefits from reducing feedback, there is some evidence that more frequent feedback might be required for the learning of complex skills. Frequent feedback appears to be less detrimental for the learning of complex tasks because feedback is generally not as prescriptive as it often is in many simple tasks. Thus, the likelihood of the learner becoming dependent on the augmented feedback and neglecting the processing of intrinsic feedback might be reduced in complex skill learning.

Implications for Music Pedagogy

Taking these findings into consideration, one might be able to model an effective teaching strategy that uses both reduced and delayed feedback. Certainly we can infer from the above-cited studies that students should be allowed to play through a piece without interruption. Also, the instructor's question "How do *you* think you played?" following this performance is more than mere rhetoric. It encourages the student to reflect and learn. Although it is often assumed that mistakes should be avoided at all costs, a teacher calling out corrections while the student is playing does not prevent errors. Moreover, as explained above, judging performance simultaneously, or giving feedback immediately afterwards, may actually hamper learning for a number of reasons: the processing of performance is disrupted, resulting in poorer mental representations; the student does not learn to judge his or her own performance; and movement stability necessary for motor learning is reduced. It should also be kept in mind that the performance being evaluated is only a *temporary* result and not necessarily a sign of learning. Thus, the student receives feedback that may be confusing or counterproductive to the learning process. In contrast, using feedback sparingly, and providing it only after the learner has had a chance to process his or her intrinsic feedback, could result in more effective learning.

Blocked Versus Random Practice

Thomas Edison's famous quote "genius is 1% inspiration and 99% perspiration" conjures up an image of hard work via a large number of repeated trials. Indeed, the most common method of practice for a musician involves repetition, based upon a series of work loops that is often described as Test-Operate-Test-Exit (TOTE) (Chaffin & Imreh, 2002). Following a run-though of the musical composition to be worked on, musicians select the passages that need improvement (Jørgensen, 2004). Although the practice session includes multiple tasks, in a typical practice regimen, learners practise (*operate* on) one task at a time. That is, when practice of one task is completed (successful *test*), the learner moves on to the next task (*exit*), and so forth, each task in sequence. Differences in expertise are noticeable in the way musicians behave in these operational phases. Novices tend to repeat the musical phrase in question until they have reached the point at which an error-free performance has become likely. In other words, a series of perfect repetitions of the passage are considered as the signal to exit the operational stage. Many practitioners assume that this type of 'blocked' practice enables the individual to concentrate on a given task. Supposedly this is more beneficial to learning than switching frequently between different tasks would be. In the following sections, we review studies that have compared the effectiveness of blocked practice schedules with those of random practice schedules, in which learners continuously switch between different tasks. Although counter-intuitive, these findings indicate that learning usually benefits more from random practice.

Experimental Findings

A study by Shea and Morgan (1979) provided the first demonstration of differential learning effects as a function of the practice schedule – the so-called "contextual interference" effect. Contextual interference refers to the interference that is created by different tasks practised in the same session. To assess the influence of contextual interference on learning, experimental studies typically compare two very different practice schedules, namely, random practice – where the interference between tasks is high – and blocked practice – where interference is low. In the Shea and Morgan (1979) study, participants practised three different versions of a barrier-knock-down task. On each task, three of six barriers had to be knocked down in a specific order as quickly as possible. A group that practised the tasks in a blocked order, where all trials on one task were completed before the participant moved on to the next task, showed more effective performance (i.e., faster movement times) during practice than a group that practised the tasks in a random order. This finding is not surprising, given that repetitive practice is "easier" than continuously changing tasks. However, when learning was assessed in retention and transfer tests, the random practice group clearly outperformed the blocked group.

The learning advantages of random as compared to blocked practice have been replicated in numerous experiments. The contextual interference effect has been observed not only for typical "laboratory" tasks – such as tracking, aiming, anticipation-timing, or sequential-timing tasks – but also for sport skills, including kayak rolls, badminton serves, and tennis ground strokes (for reviews, see Brady, 1998; Magill & Hall, 1990; Wulf & Shea, 2002). Overall, the effect has proven to be a fairly robust phenomenon.

The reason that blocked practice is commonly preferred in practical settings is presumably related to the greater improvements in performance seen during practice, as compared to more demanding practice schedules in which the tasks are frequently changed. That is, instructors tend to assume that the relatively fast performance improvements typically seen with repetitive (e.g., blocked) practice, as opposed to more varied (e.g., random) practice, reflect more effective learning. Interestingly, even learners themselves over-estimate how much they learned under blocked as compared to random practice conditions (Simon & Bjork, 2001). However, as pointed out earlier, *learning* can only be assessed under identical conditions for all groups. When the learning effects of blocked versus random practice are compared in retention or transfer tests, the initial (performance) disadvantage of random practice typically manifests itself as a learning advantage.

Explanations for the Benefits of Random Versus Blocked Practice

Several hypotheses have been put forward to explain the contextual interference effect. The most prominent ones are the *elaboration* hypothesis (e.g., Shea & Morgan, 1979), and the *reconstruction* hypothesis (Lee & Magill, 1983, 1985). According to the elaboration view, random practice promotes the use of multiple and variable information-processing strategies. This, in turn, leads to more distinctive and elaborate memory representations than blocked practice. Under random practice conditions, the different tasks to be learned reside together in short-term memory and can therefore be compared (which is not possible under blocked conditions), increasing the level of distinctiveness. Also, the use of different encoding strategies presumably leads to a more elaborate memory representation than the impoverished encoding under blocked conditions. The more distinctive and elaborate representation of the skill after random practice is assumed to be responsible for the learning advantages.

According to the reconstruction hypothesis, the interference created by random practice leads to (partial) forgetting of the action plan, or motor program, between practice trials. Therefore, the motor programs have to be reconstructed repeatedly. This is not necessary under blocked practice conditions, because the action plan is already in short-term memory. According to this view, the repeated action-plan reconstructions in random practice are supposed to be responsible for the learning advantages compared to blocked practice.

Implications for Music Pedagogy

The findings reviewed in this section help explain a common mistake made by both teachers and students: confounding performance with learning. Two situations, in which immediate performance is judged, are (a) during the lesson, when the student plays correctly immediately following instruction, and (b) during practice, after several error-free repeats. In both cases, there is the illusion that learning has taken place. Yet, both teacher and student are possibly judging success that may be the sign of temporary storage of the motor skill in short-term memory and not necessarily the sign of retention in long-term memory, let alone evidence of an elaborate mental representation that will allow for variation in the context of another musical composition or the same one in a future performance situation.

To our knowledge, no studies examining the contextual interference effect have used musicians or music-related tasks. Therefore, it may be somewhat premature to generally recommend random practice schedules. Also, the tasks practised in music tend to be relatively complex, and there are indications that random practice may lose its advantage if the tasks are very demanding and/or the performer has little or no experience with the respective tasks (e.g., Alvaret & Thon, 1999; Hebert, Landin, & Solmon, 1996; Shea, Kohl, & Indermill, 1990; for a review, see Wulf & Shea, 2002). That is, for the learning of complex skills where memory and information-processing demands are high, blocked practice (for example, use of the TOTE method) may be more effective, at least early in the learning process. However, random practice is usually more effective than blocked practice when it comes to the learning of relatively simple skills, for which the memory demands are comparatively low, or when individuals are experienced and the demands of the task are functionally reduced. Furthermore, after advanced movement patterns have been mastered, random practice may be better suited to skill level maintenance increasing durability of long-term memory. When concentration wanes during too much blocked practice of an already learned passage, improvement not only stagnates, it may also go backwards and performance may start to deteriorate. It is currently believed that this occurs when muscles tire and are replaced by other, less efficient ones; an alternative explanation is that this is the result of a decrease in attentiveness during practice, leading to a decline in otherwise optimized mental representations (Altenmüller, 2006, refers to the reversal of progress achieved when too much practice is undertaken as the “Penelope Effect”).

Current neurophysiological research provides a further angle of explanation. Whereas repeated patterns become so well rehearsed that their execution requires little attention and a minimum of brain activity (Restak, 2001), non-repetitive practice requires increased information processing. In addition, the retrieval of such patterns is highly context dependent, and therefore repetitive practice makes musicians vulnerable. For example, a small modification of tempo to accommodate for the acoustics of the concert hall, or a change in instrument response time due to the effect of ambient temperature on the instrument can already suffice to impede execution of the practised motor patterns. Random practice is a trade-mark of expert performers, especially common in jazz musicians (Norris, 2007). Music teachers should suggest a practice schedule that alternates between blocked and random work units.

Observational Practice

Demonstration followed by imitation is a commonly used method when it comes to motor skill learning, and the study of observational learning has been the focus of considerable research since the early 1960s. In general, observational practice has been demonstrated to be a viable method of practising motor skills. The observation of demonstrations by a model seems to be particularly effective for the learning of complex skills (see Wulf & Shea, 2002). Music summer schools and master classes usually feature a maestro showing pupils and the audience how a certain musical passage should sound through performance of the same. In these cases, the teacher is exhibiting a behaviour too complex to be described by words alone. Accomplished musicians working with higher-level students rely on a mixture of demonstration and metaphor to explain how a certain phrase is executed. This leaves the transfer of knowledge up to the students' observational skills and their personal ability to extrapolate an answer from the teacher's analogy. The latter, the "answer", is often something that cannot be named, although it is observable as a change in the student's behaviour, for example, the successful execution of the passage being taught. When this newly acquired skill can be repeated again and again, and even in later performance, we extrapolate that learning through observation has occurred.

Experimental Findings

Even though observational practice is generally not considered to be as effective as physical practice, it has consistently been shown to be more effective than no practice (see McCullagh & Weiss, 2001, for a review). More importantly, combining observational and physical practice can be quite effective and even result in superior learning, compared to physical practice alone (e.g., Shea, Wright, Wulf, & Whitacre, 2000; Shea, Wulf, & Whitacre, 1999). Observational and physical practice are assumed to each provide unique opportunities for learning (Shea et al., 2000). These are discussed in more detail later. In the following sections, we review findings related to the influence of the model's skill level, practice in dyads, and the effectiveness of auditory models.

Skill level of the model. It is often assumed that the observation of an expert model is more beneficial to learning than the observation of another learner. Interestingly, however, the model's skill level appears to be relatively irrelevant (e.g., Lee & White, 1990; McCullagh & Meyer, 1997). While observing a skilled model has the advantage that the learner is provided with an image of the "ideal" movement pattern, observing another learner has been shown to offer significant benefits as well. By watching a novice model, the observer is privy to at least some of the cognitive activities associated with detecting and correcting errors that are thought to be important to learning (Lee & White, 1990). In fact, it has been shown that observational practice facilitates error recognition (Black & Wright, 2000). A precondition for learners to benefit from the observation of an unskilled model is that the model's errors are easily recognizable. Alternatively, the provision of feedback about the model's performance (e.g., from an instructor) can compensate for this drawback of learning models (Hebert & Landin, 1994).

Dyad practice. Practice in dyads (or pairs) is a training method that includes observational practice as well as other factors that could potentially contribute to learning. In dyad practice, two learners practise together, typically by alternating between physical and observational practice. While one learner practises physically, the other observes, and vice versa. Sometimes learners are also encouraged to engage in a dialogue during the rest interval between practice trials (Granados & Wulf, 2007; Shea, Wulf, & Whitacre, 1999). These periods can be used, for example, to exchange movement strategies that appear to be effective or to provide feedback to the other learner. Shea et al. (1999), for example, examined the effectiveness of dyad practice for the learning of a dynamic balance task (stabilometer), which – like many other complex motor tasks – requires rest intervals between practice trials to avoid fatigue and provide relief from the high attention/concentration demands. Their results showed that practice with a partner was more effective for learning than individual practice. Figure 2 shows the average deviations of the balance platform from the horizontal across 90-second trials for a dyad and an individual practice group. Learners who had practised with a partner performed more effectively (i.e., had smaller deviations) than individual learners on a delayed retention test that was performed individually. It should also be pointed out that dyad practice protocols have the potential to not only enhance learning, but to increase the efficiency of training (Shea, Wulf, & Whitacre, 1999). As two learners can be trained in nearly the same amount of time that it would usually take to train one person, both time and associated costs could be substantially reduced by the application of dyad practice.

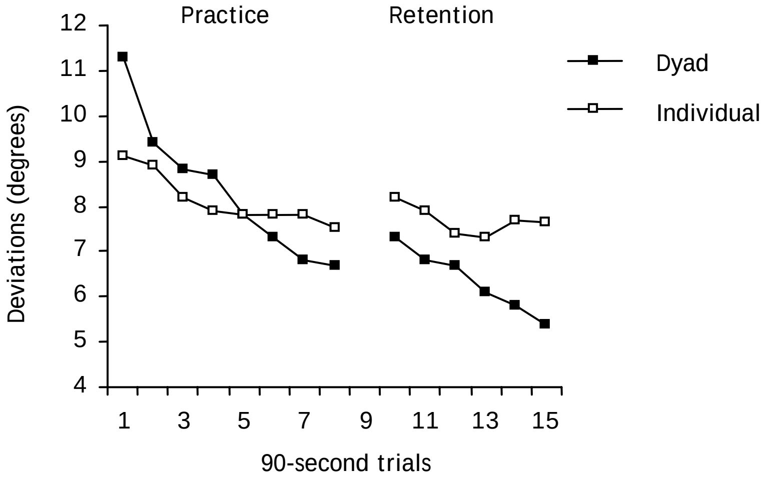

Figure 2. Balance performances (platform deviations from horizontal) of dyad and individual practice groups in the study by Shea, Wulf, and Whitacre (1999). From *Journal of Motor Behavior, 31*(2), 1999, p. 119-125. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 Eighteenth St., NW, Washington, DC 20036-1802. Copyright © (1999).

Auditory models. While there is a relatively large body of literature related to visual observation, only a few studies have examined the effects of an auditory model on learning. Anecdotal evidence suggests that providing auditory models may be rather powerful in facilitating the learning of movement sequences. For example, the Suzuki method (Suzuki, 1969) based upon the language model (Suzuki's name for the mother-tongue method is "Talent Education"), in which students are repeatedly exposed to either a parent playing a piece of music or a recorded version of it, has successfully been used to teach children how to play musical instruments (McPherson, 2007). Students are apparently able to use the memory representation, developed through the repeated exposures to the auditory model, to reproduce the musical score and make appropriate corrections, if necessary.

A few studies have experimentally examined the effects of auditory models on learning. These studies provide converging evidence that learning of movement sequences – in particular, the relative-timing structure – is enhanced by the presentation of an auditory model (e.g., Shea, Wulf, Park, & Gaunt, 2001; Lai, Shea, Bruechert, & Little, 2002). For instance, in the study by Shea et al. (2001), participants, not selected for musical ability and training, learned to produce a 1600 or 1000 ms sequence of six key presses with the same relative-timing pattern (rhythm). The absolute goal durations for the five movement segments between key presses were 300, 500, 200, 200, 400 ms for the 1600 ms task version, and 188, 312, 125, 125, 250 ms for the 1000 ms task version. In addition to visual feedback, which indicated the actual duration compared to the goal duration for each movement segment, one group was provided an auditory model before each trial. The auditory model consisted of a series of computer-tones, played in the respective (absolute and relative) goal movement times. In the first experiment, learners provided with the auditory template exhibited more effective learning of the relative-timing and absolute-timing pattern than participants not provided with the auditory template. In a second experiment, both the auditory and no-auditory template groups consisted of physical practice participants each paired with an observer during practice. The observer was privy to all instructions as well as auditory and visual information with which the physical practice participant was provided. The results again showed that the accuracy of the relative timing was enhanced by the auditory template. In fact, there was no difference between the groups that practised physically and learned through observation. However, physical practice was required to enhance absolute timing. That is, absolute timing was only improved when the auditory model was coupled with physical practice.

It is interesting to note that learners did not appear to develop a dependency on the auditory model (as is seen with concurrent feedback, for example). When the auditory model was presented prior to each practice trial, performance was enhanced almost immediately, indicating a strong guidance effect of the information. Importantly, the benefit of the auditory model carried over to the retention test where the auditory model was removed.

Explanations for the Benefits of Observational Practice

Observational practice provides the learner with an image of the goal movement. This is especially effective for the learning of complex skills, where it can provide a “picture” of how the various components of the task fit together. Like analogies, which have been shown to reduce memory demands by providing a framework in which to organize memory (e.g., Anderson & Fincham, 1994; Fery & Vom Hofe, 2000), observation may facilitate the structuring of the memories and effectively reducing the total memory demands. This phenomenon, also known as “chunking”, is a necessary part of learning, encoding and storage, and later retrieval of complex movement patterns, such as those required for fluent instrumental performance of a musical composition.

Especially early in practice, where most of the cognitive resources are required to perform a new task physically, observational practice offers the learner the opportunity to engage in information-processing activities that may not be effectively carried out otherwise (Kohl & Fisicaro, 1996; Shea, Wright, Wulf, & Whitacre, 2000). That is, by observing another performer, the learner may be able to extract important information regarding the appropriate coordination pattern – which would be difficult, if not impossible, to do while attempting a new task because of the high cognitive demands (Wulf & Shea, 2002).

Practice in dyads presumably has beneficial effects on learning that go beyond those related to observation per se. Factors that might have an impact on learning in group situations are competition, social comparison, and motivation. Furthermore, goal setting (e.g., Locke & Latham, 1985; Locke, Shaw, Saari, & Latham, 1981) might be enhanced in dyad practice situations. The direct interaction with another learner might cause individuals to set higher goals than they normally would, such as outperforming the other person. Goal setting has indeed been found to benefit the performance and learning of motor skills (e.g., Boyce, 1992; Burton, 1994; Kyllo & Landers, 1995).

Auditory models apparently facilitate the development of the movement representation – without creating a dependency on the additional information. Interestingly, for relative-timing learning, auditory models can be utilized equally effectively in physical and observational practice. In contrast, absolute timing benefits of an auditory model are only seen when it is combined with physical practice. This suggests that the execution of a movement is important with regard to the planning, execution, and/or intrinsic feedback when it comes to absolute-timing learning, but not necessarily relative-timing learning (Shea et al., 2001).

Implications for Music Pedagogy

Observational practice is a part of every musician's biography. All musicians learn from listening to and watching each other. In traditional music and jazz, the apprenticeship model of learning is based upon the student's opportunities to observe and copy adult professionals. Today's classical musicians also learn to copy their teachers' demonstrations, and this is supplemented by occasional visits to concerts, which provide additional models of expertise. This form of learning dates back to the Late Middle Ages, when the novice (apprentice) was provided with an observational model (the master craftsman or craftswoman) and on-the-job training. Moving outside of these traditions, Green (2002) recently provided interview data for observational learning, demonstrating that it is the backbone of popular musicians' learning strategies. Especially during adolescence, popular musicians rely upon group rehearsals and watching each other to improve their skills. This practice is often referred to as "informal" as opposed to "formal" music education, and these musicians refer to themselves as "self-taught", although, technically speaking, they did not learn by themselves. Aside from the benefits of observational learning mentioned above, there is also an increased intrinsic motivation to practise (Kleinen & von Appen, 2007) in the peer-group setting. These are compelling arguments that music educators could and should augment their teaching practice to create additional learning situations in which apprentices can learn from *one another* for the reasons explained in this section.

An additional incentive to employ observational learning comes out of musicians' health concerns, which only recently have become the focus of attention and research. In light of the prevalence of overuse injuries among musicians (Fry, 1986), the possibility of using observational practice to replace extended hours of physical practice is of immeasurable significance. This strategy saves wear and tear on the muscles since many of the same brain regions are activated when one watches someone else do a task, as when one does it oneself; although some muscles are enervated in the process, they are not subject to the same strain as they would be in actual training. The effectiveness of this training can be increased when slower demonstration tempos are taken, or when videotapes are replayed in slow motion. The only limitation is that there must be prior motor experience with the skill being observed, otherwise it cannot be replicated mentally (Sonnenschein, 1990). It is presumed that the activation of mirror neurons is part of the explanation as to how observational learning works. On-going research hopes to explain the phenomenon better (Bangert, 2006; Schlaug & Bangert, 2007; Nirkko & Kristeva, 2006), but musicians do not have to wait until these studies are concluded; they can take immediate advantage of this training method by including it in their current repertoire of practice techniques.

Attentional Focus

One factor that has been shown to have a significant influence on the learning and performance of motor skills is the individual's focus of attention. In most training situations, including musical practice, teachers tend to give instructions that refer to the performer's body movements. For example, a pianist will be told to hold both wrists higher when playing a scale on the black keys. A flute-player will be given instructions regarding when and how to breathe for a particular phrase. Yet, in the past few years, numerous studies have demonstrated that directing attention to one's *movements* (i.e., adopting an "internal focus") is relatively ineffective. In contrast, adopting an "external focus", or directing attention to the *effects* that one's movements have on the environment – such as the apparatus, implement, or instrument – generally results in more effective performance and learning (for a review, see Wulf, 2007a, b).

Experimental Findings

Most studies examining attentional focus effects have used relatively complex motor skills to study the effects of attentional focus instructions. For example, in the first study that demonstrated external focus advantages, a ski-simulator task was used (Wulf et al., 1998, Experiment 1). The task required participants to produce slalom-type movements with the largest possible amplitude (with a maximum of 55 cm to the left or right). The results showed that instructing performers to focus on the force they exerted on the *wheels* of the ski-simulator platform on which they were standing (external focus) – which were located directly under their feet – was more beneficial than instructing them to focus on the force they exerted with their *feet* (internal focus). As can be seen in Figure 3, the external focus group produced larger movement amplitudes on a retention test than both the internal focus and a control group without focus instructions. Thus, even though the difference in the focus of attention was rather small, it had a clearly differential effect on learning. Other studies using a variety of balance tasks have shown that learning is generally enhanced if performers are instructed to focus on the movements of the support surface (e.g., a balance board) as opposed to the movements of their feet (e.g., Totsika & Wulf, 2003; McNevin, Shea, & Wulf, 2003; for a review, see Wulf, 2007b). The benefits of directing attention to the movement effect have also been demonstrated for skills in sports such as golf (Wulf, Lauterbach, & Toole, 1999), tennis (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000), volleyball and soccer (e.g., Wulf, McConnel, Gärtner, & Schwarz, 2002). In golf, for example, focusing on the swing of the *club* has been shown to result in greater accuracy of the shots than focusing on the swing of one's *arms* (Wulf et al., 1999; Wulf & Su, 2007). Thus, a simple change in the wording of instructions can have a significant effect on performance and learning.

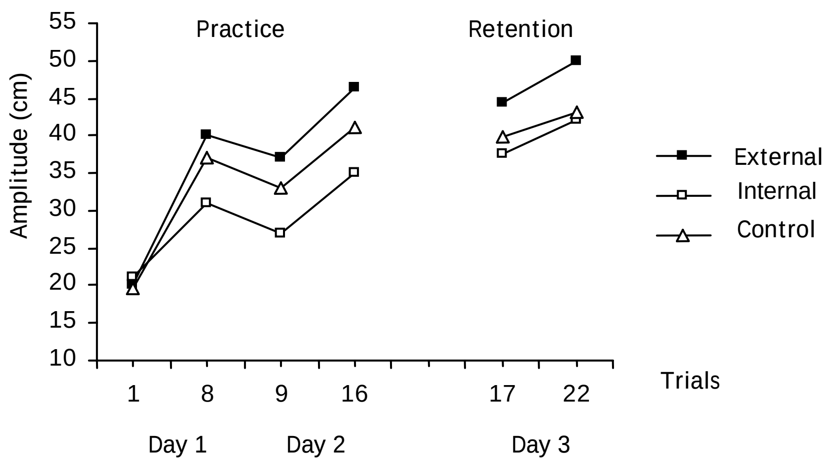

Figure 3. Movement amplitudes on a ski-simulator produced by external focus, internal focus, and control groups in the study by Wulf, Höß, and Prinz (1998). From *Journal of Motor Behavior, 30* (2), 1998, p. 169-179. Reprinted with permission of the Helen Dwight Reid Educational Foundation. Published by Heldref Publications, 1319 Eighteenth St., NW, Washington, DC 20036-1802. Copyright © (1998).

Interestingly, in studies that included control conditions without attentional focus instructions (e.g., Landers, Wulf, Wallmann, & Guadagnoli, 2005; Wulf et al., 1998; Wulf & McNevin, 2003; Wulf, Weigelt, Poulter, & McNevin, 2003), instructions to adopt an external focus resulted in more effective learning than both internal focus and no instructions. Furthermore, there is usually no difference between instructions directed at the performer's body movement (internal focus) and no instructions. This suggests that instructions inducing an internal focus are, at best, ineffective, whereas an external focus *enhances* the learning process.

Benefits of an external focus of attention have not only been observed for novices, but also for experienced performers (Perkins-Ceccato, Passmore, & Lee, 2003; Wulf et al., 2002; Wulf & Su, 2007). For example, in a study with novice and advanced volleyball players, both groups of performers benefited equally from feedback inducing an external focus rather than an internal focus in performing a volleyball serve (Wulf, McConnel, Gärtner, & Schwarz, 2002, Experiment 1). Even though the content of the feedback information was similar for external versus internal focus groups (e.g., "Shift your weight toward the target" versus "Shift your weight from the back leg to the front leg", respectively), experienced and novice volleyball players benefited from the external focus feedback. Also, expert golfers performed pitch shots more accurately when instructed to focus on the club, as compared to their arms or no instructions (Wulf & Su, 2007, Experiment 2). These studies show that, not only at the beginning stages of learning, but even at a high level of expertise, performance can be improved by inducing an external focus.

Explanations for the Benefits of an External Focus

The advantages of an external focus have been explained with the facilitation of movement automaticity (e.g., Wulf, McNevin, & Shea, 2001). Focusing on the movement effect promotes the utilization of unconscious or automatic processes. That is, the individual takes advantage of the motor system's automatic (e.g., reflexive) control capabilities – with the result that performance and learning is enhanced. In contrast, focusing on one's own movements results in a relatively conscious type of control, which tends to constrain the motor system and disrupt automatic control processes ("constrained action hypothesis"; McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001).

This notion has been supported in a variety of studies. For instance, attentional demands have been shown to be reduced (using a probe reaction-time technique) when performers adopt an external as opposed to an internal focus (Wulf, McNevin, & Shea, 2001). Furthermore, the adoption of an external focus leads to a higher frequency of movement adjustments compared to an internal focus (e.g., Wulf, McNevin, & Shea, 2001). A high frequency of adjustments is also viewed as an indication of a more automatic, reflex-type mode of control.

In addition, electromyographic (EMG) activity has been found to be reduced when participants adopt an external focus (Marchant, Greig, Scott, & Clough, 2006; Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Zachry, Wulf, & Mercer, & Bezodis, 2005). This suggests movement *efficiency* is enhanced by the external focus (for a review, see Wulf & Lewthwaite, in press). Interestingly, the increased EMG activity that is seen when the performer adopts an internal focus "spreads" to muscle groups that are not directly in the performer's focus of attention (e.g., Zachry, Wulf, & Mercer, & Bezodis, 2005). That is, an internal focus appears to constrain not only the action of the body part that the individual focuses on, but also the actions of other parts of the motor system. The superfluous muscle activity presumably creates interference, or "noise", in the motor system, which hampers fine movement control and makes the outcome less reliable.

Implications for Music Pedagogy

The findings reviewed above suggest that focusing one's attention on the movement effect, rather than on the movements themselves, results in more effective (i.e., accurate, consistent) and efficient movement patterns. Even though studies related to music performance are still outstanding, the fact that external focus benefits have been found for a variety of complex motor skills, as well as for novices and experienced performers, suggests that these findings might have important implications for the training of musicians as well. Thus, not only the timing and frequency discussed in the previous section, but also the *content* of instructional feedback is important. Teachers will ideally look for verbal instructions that direct attention away from small muscle movements or body, so that automatic motor programs are not disrupted by cognitive interference. At the same time, the externally focused music student will find and store an individual solution for a desired movement pattern implicitly – resulting in a "memory without a record" (Squire & Kandel, 1999, p. 14).

Detailed knowledge of instrumental and vocal technique is a necessary part of teacher education, since it enables the instructor to identify problems and find possible solutions. This information is then used in the selection or invention of exercises and the choice of literature. However, the student musician's awareness of individual muscle movement can be detrimental to learning. An internal focus of attention is counterproductive and might hinder the successful execution of the task, which is based upon retrieval of complex and automatic motor programs accompanied by emotion and intention to express the musical message. In fact, neuroscientists assume that mental representations of advanced performers are linked to abstract concepts of the musical work, and far removed from concrete hand and finger movements (Jäncke, 2006). Thus, when teachers give instructions, they should describe the effect to be achieved, such as "the melody line should push forward and climb towards the climax" as opposed to the specific "strike the notes harder using finger muscle and increase arm thrust towards the end of the line"; or using an image such as "the accompaniment is like a peaceful ocean of sound" rather than "pull back your left wrist to prevent the fingers from reaching the bottom of the key bed."

Sometimes computer programs are used to assist with singing training (for a review, see Hoppe, Sadakata, & Desain, 2006), and their effectiveness may also be a function of the attentional focus they induce. These programs can provide real-time visual feedback (VFB) on various aspects of performance, including pitch, timbre, shimmer, or jitter. In their review of studies that examined the usefulness of such feedback on singing performance, Hoppe et al. (2006) came to the conclusion that this type of concurrent feedback can be an effective addition to traditional singing lessons with a teacher. However, they also note that the attentional focus induced by the feedback may qualify its effectiveness: "VFB that is directed to one's own movements (e.g., the vocal tract) may be less effective than VFB on the acoustical output (e.g., real-time spectral information)" (Hoppe et al., 2006, p. 316). While this hypothesis is in line with previous findings (Shea & Wulf, 1999), it is also reasonable to assume that concurrent VFB may generally be effective because it tends to direct performers' attention to the visual outcome (i.e., externally).

Virtuosity is acquired by "doing", that is, by practising (Altenmüller, 2006), and not by being told what to do. Teachers often attempt to fix students' technical problems by using *internal* focus instructions, but these problems have been seen to solve themselves when the right *external* goal is offered. Directing one's attention away from a "difficulty" also relaxes the player; relaxation is a prerequisite for optimal learning. Also, an external focus of attention provides the appropriate mind-set for the musician that is essential for playing successfully in public. Disaster can occur when one suddenly switches from external to internal focus mid-performance, interrupting a smoothly functioning complex motor pattern that is running without conscious control. Any attempt to monitor or control individual movements, a desire driven by cognition, can be detrimental. Therefore, musicians are better off imaging the effect they want create, not trying to control exactly how they achieve the effect, and they should attempt to hear piece as a whole, not as the sum of its parts. This concentration on interpretation and music making must be rehearsed well in advance of the concert. Similarly, musicians should practise playing with a feeling of autonomy from the opinions of others. The latter is best acquired through practice that is self-motivated and self-guided, as seen in the following section.

Self-Controlled Practice

In most training situations that involve the learning of motor skills (e.g., sports, physical or occupational therapy), the instructor determines the details of the training protocol. For example, a physical therapist might prescribe the exercises he or she wants the patient to perform, the order of different exercises, and the number of sets and repetitions for each. Coaches provide feedback to athletes about correct or incorrect parts of the movement, and may give demonstrations of the goal movement pattern. Thus, instructors typically control most aspects of the training, whereas the learner assumes a relatively passive role. To a certain extent, this applies to music as well when musicians are dismissed from their lessons with an assignment book full of goals that they are supposed to tackle at home, alone. Ideally, the music teacher will spend lesson time teaching the student how to solve problems, create new tasks, and set up his/her own practice regime. Although this would benefit students at all levels, it is usually only advanced students who step out of the passive role and take responsibility for their own training sessions – despite the evidence that is the subject of this section.

The role of self-regulation, or self-control, in learning was first discussed in the literature on verbal or cognitive learning (e.g., Carver & Scheier, 1990; Paris & Winograd, 1990; Zimmerman, 1989), and there is general agreement that self-controlled learning has a beneficial effect on the learning process. In recent years, there has been increasing interest in this phenomenon in the motor learning domain as well. Accumulating evidence suggests that the effectiveness of motor skill learning can indeed be enhanced if the learner is given some control over the practice regimen. That is, compared to prescribed training protocols, giving learners a certain degree of self-control generally result in more effective learning.

Studies on self-controlled learning typically involve a “yoking” procedure, whereby each participant in a self-control group is yoked to a participant in another group. For example, if the variable to be controlled is the feedback presented after a trial, each yoked participant would receive feedback on the same trials on which her or his respective self-control counterpart had requested feedback (e.g., Trials 1, 3, 4, 7, etc.). The purpose of such a yoking procedure is to control for the amount and scheduling of feedback (or whatever factor is controlled by the learner). Because, on average, the frequency and timing of feedback are identical in the self-control and yoked groups, any group differences that emerge on retention or transfer tests can be attributed to the fact that one group had control over the feedback schedule, while the other group did not.

In this section, we review studies that have examined the effects of self-controlled practice on motor learning. These studies have focused not only on the delivery of feedback, but also on the use of physical assistance devices, and movement demonstrations.

Experimental Findings

Feedback. A number of studies have examined the effectiveness of self-controlled feedback schedules (e.g., Chen, Hendrick, & Lidor, 2002; Chiviacowsky & Wulf, 2002;

Janelle, Barba, Frehlich, Tennant, & Cauraugh, 1997; Janelle, Kim, & Singer, 1995). In one of those studies, participants practised throwing a ball at a target with the non-dominant arm (Janelle et al., 1997). One group of learners ("self-control") had the opportunity to indicate when they wanted to receive feedback regarding their movement form, or technique. If requested, the experimenter would provide feedback based on the participant's performance on the previous trials. The results showed that self-control participants demonstrated more effective learning with regard to both movement form and throwing accuracy, compared to yoked participants.

Other studies have found advantages of self-controlled feedback for the learning of sequential timing tasks (Chen, Hendrick, & Lidor, 2002; Chiviacowsky & Wulf, 2002). For example, Chiviacowsky and Wulf (2002) used a task that required participants to press four keys (2, 4, 8, and 6) on the numeric keypad of a computer keyboard in a prescribed temporal sequence. The goal movement times for each of the three movement segments (between keys) were 200, 400, and 300 milliseconds. Feedback consisted of the actual movement times, as well as the goal movement times, for each movement segment. When the production to novel goal movement times (300, 600, 450 ms) was required in a transfer test, the self-controlled feedback group again outperformed the yoked group. This finding demonstrates that the benefits of self-controlled feedback can also transfer to novel variations of the skill.

While studies on self-controlled practice have almost exclusively used adults as participants, a more recent experiment demonstrated similar benefits for children as well (Chiviacowsky, Wulf, Laroque de Medeiros, & Kaefer, 2008). In that study, 10-year old children practised tossing beanbags at a target with their non-dominant arm. The results showed that self-controlled feedback resulted in a significant learning advantage (i.e., more accurate throws) on a delayed retention test without feedback.

Assistive devices. Other studies have looked at the self-controlled use of physical assistive devices, which are often used in the learning of balance skills (Wulf, Clauss, Shea, & Whitacre, 2001; Wulf & Toole, 1999). In one study, participants practised a ski-simulator task (Wulf & Toole, 1999). The physical assistance devices used in that study were ski-poles, which generally facilitate the maintenance of balance and have been shown to enhance the learning of this task (Wulf, Shea, & Whitacre, 1998). Participants in the self-control group were allowed to choose on which trials they wanted to use the assistive devices during practice. The self-control participants showed clearly more effective learning, that is, larger movement amplitudes, than did their yoked counterparts. In a follow-up study (Wulf, Clauss, Shea, & Whitacre, 2001) it was found that self-controlled learners also demonstrated a more efficient movement technique (as indicated by the weight shift from one leg to the other). This suggests that self-control learners engage in different information-processing activities, such as a search for the optimal movement pattern, and that these activities were facilitated by their ability to choose, or not to choose, the assistive devices.

Demonstrations. One study looked at whether providing model presentations at the learners' request would enhance learning, compared to providing them without consideration for their preferences (Wulf, Raupach, & Pfeiffer, 2005). In that study, participants practised a basketball jump shot. A video of a skilled model could either be requested (self-control) or was provided at the respective times (yoked). After a seven-day retention interval, the self-control group had significantly higher form scores than the yoked group (see Figure 4). That is, despite an initial disadvantage in skill level, the self-control group showed considerably greater improvements in movement form, and demonstrated more effective learning on the retention test. Interestingly, the differential learning effects occurred despite a relatively low frequency of model presentations (5.8% of the practice trials).

Explanations for the Benefits of Self-Controlled Practice

In general, self-controlled practice conditions are assumed to enhance learning because they lead to a more active involvement of the learner in the learning process and encourage learners to take charge of their own learning process. This, in turn, might make learning more motivating and increase the effort invested in practice (Ferrari, 1996; McCombs, 1989; Watkins, 1984).

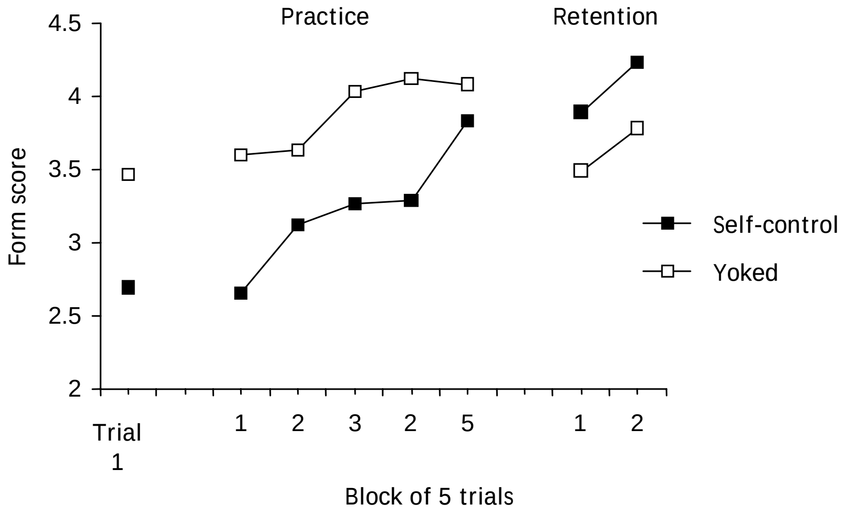

Figure 4. Movement form scores (higher scores indicate better form) of the self-control and yoked groups in the study by Wulf, Raupach, and Pfeiffer (2005). From *Research Quarterly for Exercise and Sport*, *76* (1), 2005, p. 107-111. Reprinted/adapted with permission by the American Alliance for Health, Physical Education, Recreation and Dance, 1900 Association Drive, Reston, VA 20191. Copyright (2005).

In addition, self-controlled practice conditions seem to be more in line with the learner's needs or preferences, compared to externally controlled conditions – which might also enhance learning (Chiviacowsky & Wulf, 2002). For example, with regard to the use of assistive devices, self-controlled practice might result in more effective learning, because it allows learners to explore movement strategies to a greater extent than practice without self-control does (Wulf & Toole, 1999). That is, the learner might try out a certain strategy with the assistive devices on one trial, and then without the devices on the next trial. With respect to feedback, questionnaire results (Chiviacowsky & Wulf, 2002) revealed that self-control learners (as well as yoked learners) preferred to receive feedback after a trial that they perceived as 'good'. In fact, self-control participants asked for feedback predominantly after relatively successful trials. Yoked learners, of course, did not have this opportunity. Finally, learners might extract more, or more relevant, information from model presentations when they have the opportunity to request them. For instance, self-control learners might pay particular attention to aspects of the movement they are uncertain about – either to identify errors, or to obtain confirmation that their movement is correct. In contrast, learners without the opportunity to request demonstrations might be less inclined to engage in such information-processing activities due to the unpredictability of the model presentations.

Overall, the picture that emerges from these studies is that the benefits of self-controlled feedback are due primarily to a more active involvement of the learner in the learning process, with a concomitant increase in motivation. This, in turn, seems to lead to deeper information processing and ultimately to enhanced learning. In short, a complex motor skill such as instrumental virtuosity is not a fixed ability, but “flex-ability”, and the more variations explored during practice, the better equipped the instrumentalist/vocalist will be to face the challenges of musical performance.

Implications for Music Pedagogy

While it may appear to be challenging to organise practice sessions for musicians similar to the above-described motor learning settings that often exist only in the lab, this does not mean that these results bear no significance to music learning. On the contrary, music educators can take example from these experiments and modify routines that have dominated lessons for decades. It is not only beneficial for learning when students actively request feedback, it also makes the lesson more interesting for both parties.

Some studios have a variety of assisted devices, from Music Minus One and Band-in-a-Box recordings, to midi-compatible instruments, mirrors and other training equipment. Since the value of student initiative cannot be underestimated, teachers should allow students to determine when they work with such devices. As for self-determination of the timing of demonstrations, ever more music DVDs of both contemporary and historic performances are being released and are available in school libraries for viewing or loan, or for purchase at reasonable prices. These provide students with unprecedented access to international artists across several generations; they can both hear and watch a variety of professionals performing advanced pieces of music. For works at lower levels, teachers can use video or digital cameras (or even cell phones) to make short movies, thus enabling beginners to observe a skilled model perform the piece they are working on whenever desired. In this way, modern technology can aid teaching and provide students with more autonomy in the learning process.

Students do not automatically take responsibility for what they do outside the lesson. Being on their own does not mean that they invest effort or creative energy in their practice. Following the adage “practice makes perfect”, they repeat their pieces over and over again. Repetition leads to boredom and loss of attention. These are exactly those factors that prohibit even a willing student from developing good work habits and being innovative when it comes to problem solving. Often even the so-called “good students” follow the assignment book to the letter, without meaningful work phases or flexible practice strategies. Some students ignore the teacher’s advice and just play their pieces from start to finish multiple times until their practice time is up. Others ‘play’ in the sense of play around, which can be a good motivational tool, but does not contribute much to progress in motor learning. Motor learning studies on the effectiveness of self-controlled learning suggest that music pedagogy research in the near future should address the problem described here: teachers need strategies with which to teach students how to work effectively on their own.

Summary and Conclusions

The motor learning research presented above should provide inspiration to the musician and music educator. These experimental findings present evidence of practice and instructional effects that suggest new directions in training and pedagogy. Even though experimental studies examining the learning of musical skills are still lacking, it is not too soon to take the preceding discussion of evidence regarding feedback, blocked vs. random practice order, observational practice, attentional focus, and self-controlled practice and look at its ramifications for music.

Several times in this paper we have argued that there is a big difference between performance and learning. The following scene illustrates the importance of this distinction: In answer to the teacher's question "Last week we practised this together you got it right, how could it get worse?" the student counters, "I played it better at home." The teacher is convinced that the student has not practised; the student is frustrated. Both are caught in a tango in which the traditional roles of formal, classical music training have both of them locked into steps that repeat and repeat. Both partners have mistaken temporary performance effects for long-term learning. The student believed that blocks of error-free repetition in the context of the home environment were evidence of more permanent learning. And the teacher, who was pleased with the student's run-throughs in the lesson, thought that these results were sufficient to ensure that the correct motor pattern could be repeated at home. The student was assured by the teacher's positive feedback during the lesson.

The evidence provided here suggests answers to an issue raised at the start of this paper: the optimal practice strategy. Researchers studying expertise have also affirmed many of the factors discussed here. They have identified and defined "deliberate practice" as the common denominator among experts, regardless of field of work (e.g., Ericsson, 2002; Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Römer, 1993; Lehmann, 1997). This type of practice involves concentration, building blocks of learning, guidance through constructive feedback, and emphasis on long-term goals instead of short-term performance.

All of the issues raised here, the value of professional feedback, varied practice schedules, observational practice, externally directed focus of attention, and self-controlled learning are applicable to musicians. At the core of any teacher or trainer's work is the guidance of students through high quality feedback. Teaching professionals should be prompted by the evidence presented here to review the timing and quantity of such feedback, perhaps by video taping and critically evaluating their lessons. The same flexibility is required in reviewing rehearsal habits. It will not be easy to dispense with preconceptions about the value of repetition perpetuated over centuries and experiment with variable practice, but the aforementioned studies should offer motivation for such a step. We have also seen that observational learning provides advantages through facilitation of information processing; by providing additional sources of motivation, especially through peers; creating less dependency upon the presence of a teacher; and a reduction of the danger of the "overuse" syndrome. All of these reasons may help improve the reputation of group lessons, which are largely seen as an economical rather than a pedagogical necessity.

The goal of top musical training, as in most other fields, is the ability to work independently, that is, to exhibit self-control and self-determination. The achievement of this goal is likely to be hampered by frequent feedback, for example. It inhibits the processing of intrinsic feedback and creates dependency on the teacher, and it prevents flexible practice necessary to establish the skill in a multi-faceted representation that can be modified and is not dependent upon the context in which the performance takes place. The sooner that musicians-in-training learn to be their own best critics, the less likely they are to condition themselves to hear judgmental voices during performance that undermine self-efficacy, as well as steer attention towards mistakes and internal focus, and away from the overall musical message.

On a final note: live performances are much more compelling than recorded ones. Many students at colleges and conservatories complain that their professors are unwilling to play for them or with them – although this century-old tradition is a necessary part of good instruction. Competition between students often prevents them from playing for and helping each other, although both of these are the ingredients of popular, informal music education. Following the arguments presented in this paper, an increased awareness of the importance of observation and imitation, music making within the lesson can be rediscovered as an essential part of musical training.

References

Adams, J.A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3,* 111-150.

Altenmüller, E. (2006). Hirnphysiologische Grundlagen des Übens. In U. Mahlert (Ed.), *Handbuch Üben* (pp. 47-66). Mainz: Schott.

Alvaret, J-M., & Thon, B. (1999). Differential effects of task complexity on contextual interference in a drawing task. *Acta Psychologica*, *100*, 9-24.

Anderson, J.R., & Fincham, J.M. (1994). Acquisition of procedural skills from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1322-1340.

Bangert, M. (2006). Brain activiation during piano playing. In E. Altenmüller, M. Wiesendanger, & J. Kesselring (Eds.), *Music, motor control and the brain* (pp. 173-188). Oxford: Oxford University Press.

Bilodeau, E.A., & Bilodeau, I.M. (1958). Variable frequency of knowledge of results and the learning of a simple skill. *Journal of Experimental Psychology*, *55*, 379-383.

Black, C.B., & Wright, D.L. (2000). Can observational practice facilitate error recognition and movement production? *Research Quarterly for Exercise and Sport, 71,* 331-339.

Boyce, B.A. (1992). Effects of assigned versus participant-set goals on skill acquisition and retention of a selected shooting task. *Journal of Teaching in Physical Education, 11,* 220-234.

Brady, F. (1998). A theoretical and empirical review of the contextual interference effect and the learning of motor skills. *Quest, 50,* 266-293.

Burton, D. (1994). Goal setting in sport. In R.N. Singer, M. Murphey, & L.K. Tennant (Eds.), *Handbook of research on sport psychology* (pp. 467-491). New York: Macmillan.

Carver, S., & Scheier, M.R. (1990). Origins and functions of positive and negative affects: A control-process view. *Psychological Review, 97,* 19-35.

Chaffin, R., & Imreh, G. (2002). Practicing perfection: Piano performance as expert memory. *Psychological Science, 13*(4), 342-349.

Chen, D.D., Hendrick, J.L., & Lidor, R. (2002). Enhancing self-controlled learning environments: The use of self-regulated feedback information. *Journal of Human Movement Studies, 43,* 69-86.

Chiviacowsky, S., & Wulf, G. (2002). Self-controlled feedback: Does it enhance learning because performers get feedback when they need it? *Research Quarterly for Exercise and Sport, 73,* 408-415.

Chiviacowsky, S., Wulf, G., Laroque de Medeiros, F., & Kaefer, A. (2008). Learning benefits of self-controlled knowledge of results in 10-year old children. *Research Quarterly for Exercise and Sport, 79,* 405-410.

Ericsson, K. A. (2002). Attaining excellence through deliberate practice: Insights from the study of expert performance. In M. Ferrari (Ed.), *The pursuit of excellence through education* (pp. 21-55). Mahway, New Jersey: Lawrence Erlbaum Associates.

Ericsson, K. A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*(8), 725-747.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Ernst, A. (1991). *Lehren und Lernen im Instrumentalunterricht - Ein pädagogisches Handbuch für die Praxis*. Mainz: Schott.

Ferrari, M. (1996). Observing the observers: Self-regulation in the observational learning of motor skills. *Developmental Review, 16,* 203-240.

Fery, Y.A., & Vom Hofe, A. (2000). When will the ball rebound? Evidence for the usefulness of mental analogies in appraising the duration of motions. *British Journal of Psychology, 91,* 259-273.

Fry, H. J. H. (1986). Incidence of overuse syndrome in the symphony orchestra. *Medical Problems of Performing Artists, 1*(2), 51-55.

Granados, C., & Wulf, G. (2007). Enhancing motor learning through dyad practice: Contributions of observation and dialogue. *Research Quarterly for Exercise and Sport, 78,* 197-203.

Green, L. (2002). *How popular musicians learn. A way ahead for music education.* Aldershot, England: Ashgate Publishing Limited.

Hebert, E.P., & Landin, D. (1994). Effects of a learning model and augmented feedback on tennis skill acquisition. *Research Quarterly for Exercise and Sport, 65*, 250-257.

Hebert, E.P., Landin, D., & Solmon, M.A. (1996). Practice schedule effects on the performance and learning of low- and high-skilled students: An applied study. *Research Quarterly for Exercise and Sport, 67,* 52-58.

Hogan, J.C., & Yanowitz, B.A. (1978). The role of verbal estimates of movement error in ballistic skill acquisition. *Journal of Motor Behavior*, *10*, 133-138.

Hoppe, D., Sadakata, M., & Desain, P. (2006). Development of real-time visual feedback, assistance in singing training: A review. *Journal of Computer Assisted Learning,* 22, 308-316.

Jäncke, L. (2006). From cognition to action. In E. Altenmüller, M. Wiesendanger, & J. Kesselring (Eds.), *Music, motor control and the brain* (pp. 25-37). Oxford: Oxford University Press.

Janelle, C.M., Barba, D.A., Frehlich, S.G., Tennant, L.K., & Cauraugh, J.H. (1997). Maximizing performance effectiveness through videotape replay and a self-controlled learning environment. *Research Quarterly for Exercise and Sport, 68,* 269-279.

Janelle, C.M., Kim, J., & Singer, R.N. (1995). Subject-controlled performance feedback and learning of a closed motor skill. *Perceptual and Motor Skills, 81,* 627-634.

Jørgensen, H. (2004). Strategies for individual practice. In A. Williamon (Ed.), *Musical excellence: Strategies and techniques to enhance performance* (pp. 85-103). Oxford: Oxford University Press.

Kleinen, G., & von Appen, R. (2007). Motivation und autodidaktisches Lernen auf dem Prüfstand. Zur biografischen Bedeutung des Engements in Schülerbands (Motivation and self-taught learning under scrutiny: The biographical importance of school band participation). In W. Auhagen, C. Bullerjahn, & H. Höge (Eds.), *Musikpsychologie – Musikalische Sozialisation im Kindes- und Jugendalter* (pp. 105-127). Göttingen: Hogrefe Verlag.

Kohl, R.M., & Fisicaro (1996). Response intention and imagery processes: Locus, interaction, and contribution to motor learning. *Behavioral and Brain Sciences*, *19*, 760-762.

Kyllo, L.B., & Landers, D.M. (1995). Goal setting in sport and exercise: A research synthesis to resolve the controversy. *Journal of Sport & Exercise Psychology, 17,* 117-137.

Lai, Q., & Shea, C.H. (1998). Generalized motor program (GMP) learning: Effects of reduced frequency of knowledge of results and practice variability. *Journal of Motor Behavior*, *30*, 51-59.

Lai, Q., Shea, C.H., Bruechert, L., & Little, M. (2002). Auditory model enhances relative timing learning. *Journal of Motor Behavior, 34,* 299-307.

Landers, M., Wulf, G., Wallmann, H., & Guadagnoli, M.A. (2005). An external focus of attention attenuates balance impairment in Parkinson's disease. *Physiotherapy, 91,* 152-185.

Lee, T.D., & Magill, R.A. (1983). The locus of contextual interference in motor-skill acquisition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 730-746.

Lee, T.D., & Magill, R.A. (1985). Can forgetting facilitate skill acquisition? In D. Goodman, R.B. Wilberg, & I.M. Franks (Eds.), *Differing perspectives on memory, learning and control* (pp. 3-22). Amsterdam: North-Holland.

Lee, T.D., & White, M.A. (1990). Influence of an unskilled model's practice schedule on observational motor learning. *Human Movement Science*, *9*, 349-367.

Lehmann, A. C. (1997). The acquisition of expertise in music: Efficiency of deliberate practice as a moderating variable in accounting for sub-expert performance. In I. Deliège & J. A. Sloboda (Eds.), *Perception and cognition of music* (pp. 161-187). East Sussex: Psychology Press Ltd.

Liu, J., & Wrisberg, C.A. (1997). The effect of knowledge of results delay and the subjective estimation of movement form on the acquisition and retention of a motor skill. *Research Quarterly for Exercise and Sport, 68*, 145-151.

Locke, E.A., & Latham, G.P. (1985). The application of goal setting to sports. *Journal of Sport Psychology, 7*, 205-222.

Locke, E.A., Shaw, K.N., Saari, L.M., & Latham, G.P. (1981). Goal setting and task performance. *Psychological Bulletin, 90,* 125-152.

Magill, R. A., & Hall, K. G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science, 9*, 241-289.

Marchant, D., Greig, M., Scott, C., & Clough, P. (2006, March). *Attentional focusing strategies influence muscle activity during isokinetic bicep curls.* Poster presented at the annual conference of the British Psychological Society, Cardiff, UK.

McCombs, M.L. (1989). Self-regulated learning and achievement: A phenomenological view. In B.J. Zimmerman & D.H. Schunk (Eds.), *Self-regulated learning and academic achievement theory, research, and practice: Progress in cognitive development research* (pp. 51-82). New York: Springer-Verlag.

McCullagh, P., & Meyer, K.N. (1997). Learning versus correct models: Influence of model type on the learning of a free-weight squat lift. *Research Quarterly for Exercise and Sport, 68*, 56-61.

McCullagh, P., & Weiss, M. (2001). Modelling: Considerations for motor skill performance and psychological responses. In R.N. Singer, H.A. Hausenblas, & Janelle, C.M. (Eds.), *Handbook of sport psychology* (pp. 205-238). New York: Wiley.

McNevin, N.H., Shea, C.H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research*, 67, 22-29.

McPherson, G. E. (2007, November). *Diary of a child musical prodigy.* Paper presented at the Proceedings of the International Symposium on Performance Science, Porto, Portugal.

Nirkko, A., & Kristeva, R. (2006). Brain activation during string playing. In E. Altenmüller, M. Wiesendanger, & J. Kesselring (Eds.), *Music, motor control and the brain* (pp. 189-203). Oxford: Oxford University Press.

Norris, W. (2007). *Essentials for pianist improvisers*. Berlin: Sunhazed Publishing.

Paris, S.G., & Winograd, P. (1990). How metacognition can promote academic learning and instruction. In B.F. Jones & L. Idol (Eds.), *Dimension of thinking and cognitive instruction* (pp. 15-51). Hillsdale, N.J.: Erlbaum.

Park, J-H., Shea, C.H., & Wright, D.L. (2000). Reduced frequency concurrent and terminal feedback: A test of the guidance hypothesis. *Journal of Motor Behavior*, *32*, 287-296.

Perkins-Ceccato, N., Passmore, S.R., & Lee, T.D. (2003). Effects of focus of attention depend of golfers' skill. *Journal of Sport Sciences, 21,* 593-600.

Restak, R. (2001). *Mozart's brain and the fighter pilot: Unleashing your brain's potential*. New York: Harmony Books.

Richter, C. (2001). Meisterlehre – Auslaufmodell oder hochschuldidaktisches Konzept? (The Master Craftsmen Teaching Approach and University System). In P. Röbke (Ed.), *Meisterlehre und Kunstuniversität* (pp. 33-50). Wien: Universität für Musik und darstellende Kunst Wien (Eigenverlag).

Salmoni, A.W., Schmidt, R.A, & Walter, C.B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin, 95,* 355-386.

Schlaug, G., & Bangert, M. (2007). Neural correlates of music learning and understanding. In W. Gruhn & F. H. Rauscher (Eds.), *Neurosciences in music pedagogy* (pp. 101-120). New York: Nova Science Publishers, Inc.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82,* 225-260.

Schmidt, R.A. (1991). Frequent augmented feedback can degrade learning: Evidence and interpretations. In J. Requin & G.E. Stelmach (Eds.), *Tutorials in motor neuroscience* (pp. 59-75). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Schmidt, R.A., & Lee, T.D. (2005). *Motor control and learning: A behavioral emphasis* (4th ed.). Champaign, IL: Human Kinetics (193-206, 338-343).

Schmidt, R.A., & Wulf, G. (1997). Continuous concurrent feedback degrades skill learning: Implications for training and simulation. *Human Factors, 39,* 509-525.

Shea, C.H., Kohl, R, & Indermill, C. (1990). Contextual interference: Contributions of practice. *Acta Psychologica, 73,* 145-157.

Shea, C.H., Wright, D.L., Wulf, G., & Whitacre, C. (2000). Physical and observational practice afford unique learning opportunities. *Journal of Motor Behavior, 32*, 27-36.

Shea, C.H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science, 18,* 553-571.

Shea, C.H., Wulf, G., Park, J.-H., & Gaunt, B. (2001). Effects of an auditory model on the learning of relative and absolute timing. *Journal of Motor Behavior, 33,* 127-138.

Shea, C.H., Wulf, G., Whitacre, C.A. (1999). Enhancing training efficiency and effectiveness through the use of dyad training. *Journal of Motor Behavior, 31,* 119-125.

Shea, J.B., & Morgan, R.L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory, 5,* 179 -187.

Simon, D.A., & Bjork, R.A. (2001). Metacognition in motor learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27,* 907-912.

Sonnenschein, I. (1990). Mentales Training in der Instrumentalausbildung (MTI). *Psychologie in Erziehung & Unterricht*, *32,* 232-234.

Squire, L. R., & Kandel, E. R. (1999). *Memory: From mind to molecules*. New York: Scientific American Library.

Suzuki, S. (1969). *Nurtured by love: A new approach to education*. New York: Wiley.

Swinnen, S.P. (1996). Information feedback for motor skill learning: A review. In H.N. Zelaznik (Ed.), *Advances in Motor Learning and Control* (pp. 37-66). Champaign, IL: Human Kinetics.

Swinnen, S., Schmidt, R.A., Nicholson, D.E., & Shapiro, D.C. (1990). Information feedback for skill acquisition: Instantaneous knowledge of results degrades learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 706-716.

Thorndike, E.L. (1927). The law of effect. *American Journal of Psychology, 39,* 212-222.

Totsika, V., & Wulf, G. (2003). The influence of external and internal foci of attention on transfer to novel situations and skills. *Research Quarterly for Exercise and Sport, 74,* 220-225.

Vance, J., Wulf, G., Töllner, T., McNevin, N.H., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior, 36,* 450-459.

Vander Linden, D.W., Cauraugh, J.H., & Greene, T.A. (1993). The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Physical Therapy, 73,* 79-87.

Watkins, D. (1984). Students' perceptions of factors influencing tertiary learning. *Higher Education Research and Development, 3,* 33-50.

Winstein, C.J., Pohl, P.S., Cardinale, C., Green, A., Scholtz, L., & Waters, C.S. (1996). Learning a partial-weight-bearing skill: Effectiveness of two forms of feedback. *Physical Therapy*, *76*, 985-993.

Winstein, C.J., & Schmidt, R.A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 677-691.

Wulf, G. (2007a). Attentional focus and motor learning: A review of 10 years of research (Target article). *E-Journal Bewegung und Training*, 1-11.

Wulf, G. (2007b). *Attention and motor skill learning.* Champaign, IL: Human Kinetics.

Wulf, G., Clauss, A., Shea, C.H., & Whitacre, C. (2001). Benefits of self-control in dyad practice. *Research Quarterly for Exercise and Sport, 72*, 299-303.

Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior, 30,* 169-179.

Wulf, G., Lauterbach, B., & Toole, T. (1999). Learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport, 70,* 120-126.

Wulf, G., Lee, T.D., & Schmidt, R.A. (1994). Reducing knowledge of results about relative versus absolute timing: Differential effects on learning. *Journal of Motor Behavior, 26,* 362-369.

Wulf, G., & Lewthwaite, R. (in press). Effortless motor learning? An external focus of attention enhances movement effectiveness and efficiency. In B. Bruya (Ed.), *Effortless Attention: A new perspective in the cognitive science of attention and action.* Cambridge, MA: MIT Press.

Wulf, G., McConnel, N., Gärtner, M, & Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *Journal of Motor Behavior, 34,* 171-182.

Wulf, G., & McNevin, N.H. (2003). Simply distracting learners is not enough: More evidence for the learning benefits of an external focus of attention. *European Journal of Sport Science, 3,* 1-13.

Wulf, G., McNevin, N.H., Fuchs, T., Ritter, F., & Toole, T. (2000). Attentional focus in complex motor skill learning. *Research Quarterly for Exercise and Sport, 71,* 229-239.

Wulf, G., McNevin, N.H., & Shea, C.H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology, 54A,* 1143-1154.

Wulf, G., Raupach, M., & Pfeiffer, F. (2005). Self-controlled observational practice enhances learning. *Research Quarterly for Exercise and Sport, 76,* 107-111.

Wulf, G., & Schmidt, R.A. (1989). The learning of generalized motor programs: Reducing the relative frequency of knowledge of results enhances memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 748-757.

Wulf, G., Schmidt, R.A., & Deubel, H. (1993). Reduced feedback frequency enhances generalized motor program learning but not parameterization learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1134-1150.

Wulf, G., & Shea, C.H. (2002). Principles derived form the study of simple motor skills do not generalize to complex skill learning. *Psychonomic Bulletin and Review, 9,* 185-211.

Wulf, G., & Shea, C.H. (2004). Understanding the role of augmented feedback: The good, the bad, and the ugly. In A.M. Williams & N.J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 121-144). London: Routledge.

Wulf, G., Shea, C.H., & Park, J.-H. (2001). Attention in motor learning: Preferences for and advantages of an external focus. *Research Quarterly for Exercise and Sport, 72,* 335-344.

Wulf, G., Shea, C.H., & Whitacre, C.A. (1998). Physical guidance benefits in learning a complex motor skill. *Journal of Motor Behavior, 30,* 367-380.

Wulf, G., & Su, J. (2007). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport, 78,* 384-389.

Wulf, G., & Toole, T. (1999). Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. *Research Quarterly for Exercise and Sport, 70,* 265-272.

Wulf, G., Weigelt, M., Poulter, D.R., & McNevin, N.H. (2003). Attentional focus on suprapostural tasks affects balance learning. *Quarterly Journal of Experimental Psychology, 56,* 1191-1211.

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67,* 304-309.

Zimmerman, B.J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology, 81,* 329-339.

GABRIELE WULF, Ph.D., is a professor in the Department of Kinesiology at the University of Nevada, Las Vegas. She has more than 100 published articles in the area of motor skill learning. In addition, she is the author of a recent book, entitled *Attention and Motor Skill Learning* (Human Kinetics, 2007). Dr. Wulf has been a section editor for *Research Quarterly for Exercise and Sport* and has been an editorial board member for *Journal of Motor Behavior, Human Movement Science, International Journal of Fitness,* and *Zeitschrift für Physiotherapeuten*, as well as an international advisory board Member for *Physiotherapy.* She also served as secretary and treasurer from 2002 to 2004 for the North American Society for the Psychology of Sport and Physical Activity.

ADINA MORNELL is a classical pianist with a doctorate in Music Psychology. She is Professor and Chairwoman of the Department of Instrumental and Vocal Pedagogy in the Institute of Music Education at the University of Music and Dramatic Arts Graz, Austria. Her book on stage fright, *Lampenfieber und Angst bei ausübenden Musikern*, is one of the few scientific publications on the topic in the German language. In addition to her empirical research in musical performance and expertise and her career as a concert artist, she also offers courses for musicians and music teachers, as well as for executives and managers, at universities and other institutions of higher education in both Europe and the United States.