Full-Length Article

From Music to Medicine Part II: *Differences in practice behaviors between expert musicians and non-musicians when learning a basic surgical skill*

Gilles Comeau[1, 2], Jillian Beacon[2,3], Erin Dempsey[3], Mikael Swirp[2], Fady Balaa[4], Donald Russell[2,5], Kuan-chin Jean Chen[6],
1 School of Music, University of Ottawa, Ottawa, Canada
2 Piano Pedagogy Research Laboratory, University of Ottawa, Ottawa, Canada
3 School of Human Kinetics, University of Ottawa, Ottawa, Canada
4 Department of Surgery, University of Ottawa, Ottawa, Canada
5 Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, Canada
6 Department of Emergency Medicine, University of Ottawa, Ottawa, Canada

Abstract

Background: Researchers have hypothesized that years of daily practice on a musical instrument may lead to increased efficiency in practice behaviors during the learning of other fine motor skills [1]. Practice strategies in music have also been considered a suitable model for surgical training [2] and some believe that surgical outcomes might be improved by adopting musicians' practice strategies [3].

Objective: This study examines the practice behaviors of expert musicians attempting to learn a basic surgical skill, as a way to detect possible transfer of practice habits across domains. This paper investigates whether musicians differ from a control group in their selection and application of practice strategies, whether there are relationships between the choice of practice behaviors and performance scores, whether musicians progress more rapidly through the different phases of learning and, whether relationships exist between those who reach automaticity sooner and their choice of practice behaviors.

Methods: Participants' practice sessions during a knot-tying task (taught via instructional video) were video-recorded and treated according to the method of thematic analysis [4]. Two evaluators, through an iterative process, performed coding. Statistical and descriptive analyses were conducted on practice behaviors. Information was also collected on instructional video navigation so that the use of replay, pause, rewind or fast-forward could be investigated.

Results: Musicians and the control group participants favored different practice behaviors. This was demonstrated in their choice of strategies, the importance they gave to each strategy, and the way they used the strategies over the two practice sessions. There was evidence that the group of expert musicians applied better practice strategies as the choice of practice behaviors appeared to be related to performance scores and their capacity to reach automaticity. The differences between participant groups in terms of their performance of the task were reported in Part 1 of this study.

Conclusion: Our results suggest that music experts may be applying practice strategies developed during their music studies toward learning a novel surgical skill. This raised the possibility that practice skills developed through years of dedicated work at their musical instrument, might be transferable when learning a motor skill in a different domain.

Keywords*: practices, practice strategies, transfer of practice habits, learning strategies, phases of learning*

multilingual abstract | **mmd.iammonline.com**

Introduction

The medical field often claims that musicians' motor skills put them at an advantage when learning surgical skills [3,5,6]. This can be explained by the fact that individuals have a set of abilities that they bring with them and use when learning a new task [7]. It suggests that musicians' proficiency in playing their instruments is beneficial when learning refined motor skills in another domain. In part 1 of this study, [8] we investigated how participants with piano expertise and participants with no formal music training learned to tie a surgical knot. The results showed that compared to a control group, musician participants performed surgical knots faster and received higher scores for quality of performance, and the difference between the two groups was statistically significant. It appears that musical training in piano could be of benefit in the initial stage of learning basic surgical skills. This indicates that some aspects of a musicians' skillset – such as fine motor control, bi-manual dexterity and good hand-eye

PRODUCTION NOTES: Address correspondence to:
Gilles Comeau, E-mail: gcomeau@uottawa.ca | COI statement: The authors declared that no financial support was given for the writing of this article. The authors have no conflict of interest to declare.

coordination – might be transferrable to an ostensibly disparate domain.

However, motor skills might not be the only factor at play. Another factor that provides expert musicians an advantage in procedural skill acquisition is the highly efficient practice strategies that they have acquired over the years, and expert musicians' daily structured practice regime could be of assistance when learning motor skills in other domains. New learnings happen when old knowledge is applied to a new situation [9]. This could include not only previously acquired motor skills, but could also include practice strategies and practice habits. In order to adapt more readily and easily to a new task, a learner must apply the appropriate learning approach to the activity and the situation. Learners who have developed good practice strategies might make better gains in acquiring a new motor skill by recalling practice behaviors related to the present task, by remembering efficient procedures for similar circumstances, and by recollecting how to best use feedback and self-regulated behavior for evaluating and improving the new task. Practice strategies used efficiently could be of great benefit to learners trying to master a new motor skill.

Researchers have in fact hypothesized that years of regular practice on a musical instrument may lead to increased efficiency during the learning of other fine motor skills [1] and links have even been made between musicians' practice expertise and medical training. McCaskie and colleagues [2] acknowledge that the role of deliberate practice in music learning might be a suitable model for medical training, and various music learning strategies may be applicable to surgeons' training. Rui and colleagues [3] recognize that critical parallels exist between surgical and expert musical performance and it may be possible to "improve surgical outcomes by adopting musicians' strategies". In addition, it has been shown that "deliberate practice" helps with the acquisition and maintenance of expert performance in music [10] but also clinical skills development [11].

However, despite the fact that surgical and musical performance both require extensive training and dedicated practice to achieve and maintain expertise [3,10,12-14], no studies have examined how musical experts would structure their practice session or which practice behaviors they would use when attempting to learn to do a novel surgical task. The aim of this study is to investigate if there could be any evidence of transfer of practice strategies across domains.

Motor skill learning

Motor skills are "well-adjusted muscular performances" [15] acquired gradually with training [7]. Motor skill learning can be understood as the difference between the way a person performs a new task (i.e., in a slow, error-prone, and effortful manner) and the way they perform the task after training or practice (i.e., quickly, accurately, and with little effort) [16]. The practice effort aims at adopting the appropriate sequence of movements and obtaining consistency and stability in the execution. Repeated practice leads to improved performance and the process is continued until a sequence of movements becomes a well-executed behaviour performed effortlessly [17]. Motor skill is achieved only after a person undergoes a series of stages, referred to as the phases, of skilled learning.

According to Fitts and Posner [18], motor learning follows a three-phase progression where a learner advances from an initial stage that requires attention and focus to an advanced stage where the skills are produced with fluidity and automaticity. The early phase, referred to as the cognitive phase, is when the individual tries to understand the task that needs to be done. In this early stage, instructions and demonstrations are most important for the development of an executive program that will make it possible to complete the task at hand. The learner must identify and try out different strategies, recalling "old" motor skill habits and already known motor sequences. The intermediate phase, referred to as the associative phase, is when motor patterns from the previous phase are tried out, and new patterns start to emerge as the individual searches the appropriate strategies that will produce adequate results. Good strategies are retained and inefficient strategies are discarded. Errors are gradually eliminated, more subtle adjustments are made and movements become more consistent. The final phase, referred to as the autonomous phase, is when the learner can complete the task without having to rely so much on cognitive control. Speed and efficiency continue to increase during this phase, but at a slower rate than in previous phases, and automatic processing is now at play, giving fluency, fluidity and efficiency to the motor sequence. It is important to acknowledge, however, that while the model identifies three phases of learning, these are not distinct stages, as skill learning is essentially a continuous process. It is important to approach motor learning as something that occurs through gradual shifts in the learning progression. The characteristics of the transition from an initial period when an individual must exert some effort to encode a skill – through observation, instruction, and trial and error – to an automatic processing of the task, are well-acknowledged in the literature. Although Fitts and Posner's model is over 50 years old, the same basic progressions of stages are still held by researchers conducting studies on motor learning [19-23].

Practice behaviors

According to Bernstein [24], the process of practice towards the acquisition of a new motor skill can be explained by the "gradual success of a search for optimal motor solutions to the appropriate problems" – therefore, when properly done, practice does not consist "in repeating the means of solution of a motor problem time after time, but in the process of solving this problem again and again by techniques which we changed and perfected from repetition to repetition" [25]. There is evidence demonstrating that it is the quality of practice and not the quantity of practice that predicts performance success [26,27]. In music for example, it has been shown that strategies employed during practice are more determinative of performance quality than how much or how long musicians practiced [28,29]. This points to the importance of examining practice behaviors in order to better understand strategies that are at play when learning a novel task.

Not many studies have examined the various practice behaviours displayed by individuals as they freely practice a novel motor task. Some of the best examples of practice behavior studies come from the music domain [30-36]. However, few studies have incorporated measures of performance achievement [37,38]. For example, Miksza [39] examined video observations of high school woodwind players as they practiced a new etude and found correlations between performance achievement and certain practice behaviors, such as slowing down and repeating small sections. In a similar study with collegiate brass players [40], this time using Ericsson's model of deliberate practice to frame his research, he found correlations between performance achievement and practice strategies related to deliberate practice. Wulf and Mornell [41] synthesized the literature on motor learning and made recommendations for music students about the best ways to practice. In the field of medicine, Spruit and colleagues [22], reviewed the literature on procedural motor skills and summarized the training and practice factors pertaining to efficiency in acquiring surgical skills. It is interesting to note that the practice recommendations are similar between the music literature and the surgical papers.

Research questions

Strong parallels exist between surgical and musical performance regarding extensive training and practice. However, no study so far has provided evidence that previously acquired practice skills obtained through musical training translates into improved practice behaviors when learning a new medical procedural skill. The current study investigates differences between expert musicians and a control group when acquiring a novel surgical skill. The main research questions were formulated as follows:

Q-1: Do expert musicians differ from non-musicians in their manual dexterity? Hypothesis: We expected musicians to score higher in tests that evaluate a subject's fine motor skills. This question is important to establish if there were initial differences between the fine motor dexterity skills of the musician and control groups.

Q-2: Do expert musicians differ in their selection and application of practice strategies? Hypothesis: We expected to see differences in the choice of practice strategies adopted by musicians.

Q-3: Is there any relationship between practice behaviors adopted by musicians and non-musicians, and their performance scores (time to complete the task and quality of the performance)? Hypothesis: We expected to find positive correlations between certain types of practice behaviours and the success at learning the task, and we expect musicians to select the types of practice strategies that contribute to better performance score.

Q-4: Do expert musicians progress more rapidly through the different phases of learning? Hypothesis: We expected to see musicians reaching the rehearsal phase and automaticity phase sooner based on our expectation that they would have different practice behaviours.

Q-5: Is there any relationship between the participants who reached rehearsal and automaticity phases and their choice of practice behaviors? Hypothesis: We expected to find positive correlations between certain types of practice behaviours and automaticity, and we expect musicians to select the types of practice strategies that contribute to automaticity.

Methods

Participants

40 university students (ages 18 to 28) were recruited to participate in this project. Each participant filled out a general questionnaire to collect demographic data and their music background so that we could confirm that we had two distinct groups: 20 advanced piano students with strong performance skills (all had reached an expert level with ten or more years of training, had achieved Royal Conservatory of Music of Canada grade 8 level or above, still practiced regularly and most were currently studying at the university level) and 20 university students with either minimal training (no piano training and less than 2 years of other types of musical training) or no formal training in music[1]. Due to technical video recording issues, we analysed the performance of 19 musicians (days 1 and 2) and 19 control participants (day 1) / 18 control participants (day 2).

Preliminary tasks: Pegboards and Frostig Movement Skills Test

Before examining practice behaviours of our participants learning a new motor task, we sought to establish if there were initial differences between the fine motor dexterity skills of the musician and control groups. Two standard pegboard tests were administered: the Perdue pegboard [42,43,44] and the Grooved pegboard [45,46,47]. These are two of the most extensively used test for measuring manual dexterity, and based on the evidence available, they have been the most extensively studied, have good validity and reliability, and have fewer potential confounding variables

[1] Participant variables that may have had an effect on the learning and performance of the tasks are discussed in part 1.

[48]. To test coordination involving motor sequencing, an item from the Frostig Movement Skills Test was administered: Fist/Edge/Palm [49]. Test descriptions and the administrative procedure can be found in Appendix A.

Main task: Surgical knot-tying
Participants learned how to perform a basic surgical knot on a teaching board by watching a video tutorial containing a visual demonstration accompanied by verbal explanations. See Figure 1 for a picture from the instructional video and a participant performing the knot. Only one other person, a research assistant was present in the room during the session. No augmented feedback was provided and to make sure that the condition was the same for all participants, no questions about the task could be asked to the research assistant. Participants did not know they were being observed for analysis of how they practiced the task (they knew only that first they are given practice time, then would perform the task again as a test which would be evaluated). The knot task was a two-handed square knot with flat throws. Participants had to complete a total of 4 knots. Two sessions were held on two consecutive days. On the first day, participants watched the tutorial video, then were given 10 minutes to learn and practice the task, and finally they had to perform the task as a test. On the second day, they were tested upon arrival to determine how much skill was retained, then they were given a practice period of 10 minutes, and tested again. Three features characterise the task of this study: observational learning, emphasis on the practice sessions and inherent feedback.

Observational learning
Demonstration followed by imitation is a commonly used method for motor skill learning. According to Bandura [50,51], observers can acquire a cognitive representation of a task by witnessing a model's performance. This cognitive representation can be verbal and/or visual and will guide the observers when they are practicing the task. They will use this cognitive representation as a standard against which detection and corrections of errors will be made. They selectively attend to particular features of a demonstration to create a cognitive representation, and based on this representation, they refine their new skill through practice and comparison to the model. Therefore, by observing another performer, the learner is able to gather important information regarding the appropriate sequence of movements. Observational learning has been shown to be a viable method for learning motor skills [41,52]. More specifically, Landers and Landers [53] have demonstrated that learners who are exposed to an expert model performed better on a motor skill task than those who were not exposed to the model. Zimmerman and Rosenthal [54] have demonstrated that modeling accompanied by verbal explanation displays the highest level of skill proficiency when compared to other approaches.

Figure 1. *A screen capture from the instructional video (left) and from the video recording of a participant performing the knot (right).*

Emphasis on practice sessions
This study investigates practice behaviours; therefore, the focus of our observation is on the 10-minute practice periods on days 1 and 2. The task is a self-paced activity where learners can progress at their own speed. These practice sessions were completed in the same environment and the task could be repeated as many times as a participant wishes within the time frame allowed. Participants had access to the video tutorial at all times during practice periods, but not during testing periods. They could replay, pause, rewind or fast-forward the video. All practice sessions were recorded for later assessment.

Inherent feedback
During the learning process of any motor skill, feedback is an essential element that tells the learner how well the task was completed. According to Fitts & Posner [18], it is possible to identify two types of feedback. The first type is inherent or intrinsic feedback that arises naturally as the consequence of the movement itself. It is characterised by the sensory information that tells the learner how well the task was completed (i.e. kinaesthetic cues from the muscles and joints; information about location and rate of movement) and by evidence of results (i.e. what the learner can see) as the task is being processed. The second type is called augmented feedback and refers to information that supplements or "augments" the inherent feedback. It is extrinsic to the learner and depends on external cues coming from an external source that comments on the quality of the performance. Inherent feedback can be enough to master a motor sequence and complete a motor task, but augmented feedback may be needed to refine the motor skills or define specific parameters considered necessary for success. Also, augmented feedback decreases the amount of time needed to master a motor skill and increases the performance level of the learner. In this study, no augmented feedback was provided to participants – throughout all of the practice sessions, participants were relying on inherent feedback only.

Evaluating practice strategies

To investigate participants' practice strategies during the knot-tying task, each practice sessions was video recorded. Practice behaviors were identified by the same two observers for the entire study and verified by the other authors of this paper, followed by analyses conducted to find out if musicians proceeded differently than members of the control group when learning the task. Our study is based on video analysis with coding selection generated from the data and characteristics associated with the phases of learning generated from existing literature. The evaluation process is based on qualitative content analysis.

Video analysis

Over the past decades, video analysis has emerged as a powerful tool for research, as video "offers a 'microscope' for an in-depth study of the on-going production" [55]. Video analysis is a common method in research examining practice behaviors in music [39,40] and is a valid alternative to on-site evaluation for assessing psychomotor surgical skills [55].

Coding selection

Video recording were treated according to the method of thematic analysis described by Huberman and Miles [4]. Therefore, our coding was not predefined but was generated from the data with the aim of producing a small list of practice strategies that explained as much of the data as possible. Both observers watched the videos independently and wrote descriptions of the participants' actions as well as explanation of how the participants used the video recording (i.e. play, pause, rewind, no video). Both observers met to report their work and they created a list of practice strategies that became the initial coding list. One observer reviewed all the videos, creating transcriptions of the participants' activities based on the newly created coding list. If participants did something outside of the coding list, the observer transcribed those actions using descriptive language. The second observer reviewed all transcripts while watching the videos to ensure accuracy and consistency. This second observer; either approved the selected strategies, modified certain strategies or added to the strategies already identified. These practice strategies were then subjected to an iterative process in which they were revisited, revised and modified as familiarity with the videos increased. Throughout the entire process, observers met as often as needed to solve any discrepancies.

Characteristics of the phases of learning

The literature on skill learning [7,18,21] was consulted to select practice behaviors that would most appropriately identify the different stages of learning. Observable characteristics for each of the stages were discussed and approved by both observers and by other authors of this study. Once this framework was adopted full reviews of all of the videos were evaluated by both of the observers. The same process was followed rigorously for each participant. Observer one would first indicate in her observation notes that a participant had "reached" or "approached" rehearsal or automaticity. Then observer two would review the video to confirm the time-stamp for each of observer one's observation and determined if the observation revealed a rehearsal or automaticity behaviour as originally indicated by the first observer. Both observers agreed in almost every case, and met to resolve any discrepancies.

Qualitative content analysis

For this investigation, we decided to use a qualitative content analysis approach based on written transcripts of practice instead of a quantitative analysis of specific behaviors. We could not accurately count the specific number of times a strategy occurred and we could not record precisely the total number of seconds spent in each practice strategy because the boundary of when a participant began using a strategy and then terminated using one are not always clearly defined. Most participants fluidly moved from one strategy to another, with sub-strategies often occurring concurrently within the context of a larger, primary strategy. To employ the approach of counting the usage and duration of each strategy would require the artificial imposition of confinements on strategies, instead of respecting the inherent ambiguity of their boundaries. This would distort the results.

Performance scores

The present study is part of a larger research project where we explored whether musicians could learn a surgical knot more effectively than non-musicians. The two test parameters measured were time to task completion and an OSATS (Objective Structures Assessment of Technical Skills) score. The results were reported in part 1 of this study [8]. Therefore, the performance scores (for the same sample of participants) from the previous analysis will be used in this study to examine correlation between practice behaviors and performance achievements.

Statistical Analysis

Statistical analysis was performed using SPSS Version 25 (SPSS, Inc., Chicago, Ill.). For group comparisons of normally distributed continuous data (verified using the Shapiro-Wilk test), the independent-samples t-test was used; for cases with sample sizes less than 7, we presented mean values but did not perform the t-test. For non-normal data, the Mann-Whitney U test was used. For comparisons of distributions of practice strategies used we used Fisher's exact test. All tests were 2-sided and $p < .05$ were considered statistically significant.

Video navigation

Participants were allowed to use the instructional video as they wished during both 10-minute practice sessions. Their use of the video was documented by an online video player (developed specifically for this project),that recorded the time when the play/pause button was pressed and associated video time when that occurred. Navigation was then plotted to show a participant's video use (see Figure 2). These plots allowed us to observe when the video was paused (indicated by a flat horizontal line), played (indicated by a sloped line), or skipped ahead or back (indicated by a vertical line).

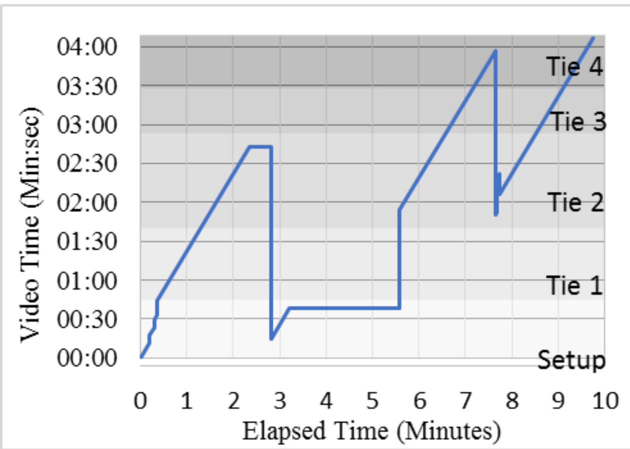

Figure 2. *One participant's video use plot.*

From each plot, we extracted the number of pauses, total pause time, total playing time and number of replays (when a participant replays a section of the video that was already played). We then used the Mann-Whitney U test to compare the musicians and control group to determine if their video use differed in terms of these parameters.

Results

Pegboard and Hand Gestures

The pegboard and hand-gesture data were non-normal; therefore, we used the non-parametric Mann-Whitney U test to compare the group of musicians (MUS) and the control group (CON); results are shown in Table 1.

There were no statistically significant differences between the groups for any of the pegboard tests. The musicians performed significantly better in the hand-gesture test in both hands, and also exhibited significantly less difference between the dominant and non-dominant hands.

Selection of Practice Strategies

Practice strategy tally

The number of different practice strategies used at least once during the practice sessions was compared using an independent-samples t-test. See Appendix B for the identification and definition of the strategies and Table 2 for the comparison of number of strategies used by musicians and control group participants.

Table 1. *Pegboard and Hand Gesture Statistical Results Comparing MUS and CON*

Test	*Median* MUS	CON	*U*	*Z*	*p*
Grooved Pegboard (Score = Time, Seconds)					
Insert, Dominant Hand	58.0	62.5	176.5	0.64	0.52
Insert, Non-dominant Hand	62.5	62.5	191.5	-0.23	0.82
Insert, Difference Between Hands	3.5	4.0	192.5	-0.20	0.84
Remove, Dominant Hand	23.0	22.0	193.0	-0.19	0.85
Remove, Non-dominant Hand	22.0	22.0	178.0	-0.60	0.55
Remove, Difference Between Hands	0.0	0.5	164.5	-0.97	0.33
Purdue Pegboard (Score = No. of Placements)					
Dominant Hand	15.0	14.0	197.0	-0.08	0.93
Non-dominant Hand	14.0	13.5	167.5	-0.90	0.37
Difference Between Hands	0.5	1.5	168.0	-0.88	0.38
Both Hands in Unison	11.5	11.0	144.0	-1.56	0.12
Assemblies	10.0	10.0	155.0	-1.25	0.21
Hand Gesture: Fist/Edge/Palm (Score = No. of Gestures)					
Dominant Hand	15.0	10.5	86.5	-3.08	0.002
Non-dominant Hand	14.0	12.5	120.5	-2.17	0.03
Difference Between Hands	-0.5	-1.5	338.0	-1.97	0.05

Table 2. *Comparison of mean number of strategies used by each group.*

	MUS		*CON*				
	M	*SD*	*M*	*SD*	*t*	*df*	*p*
Day 1	5.37	2.00	5.32	2.06	0.080	36	0.937
Day 2	5.21	1.62	4.22	1.35	2.009	35	0.052

M = mean, *SD* = Standard Deviation

On day 1, there was no difference between the two groups in terms of the number of practice strategies used. On day 2, the number of strategies used decreased for the control group but not the musicians. As such, the number of strategies used by the control group on day 2 is less than that of the musicians; the difference is not significant although the *p* value is very close to .05.

Breakdown of strategies used by each group

We tallied the number of participants from each group who used each particular strategy. Figure 3 shows the comparison of musicians and control group in terms of percentage of participants from each group because in the case of day 2, we did not have equal group sizes. We tested for the significance of the association between practice strategies used and experiment group using a Fisher's exact test. The strategies are shown in order of frequency of use.

There are some noticeable differences between the groups. Significantly more musicians use 'practice without video' and 'reviewing / slow practice' on day 2. More musicians used 'trial and error' on day 2; however, the difference between groups was not significant ($p = .09$). It was also evident that more members of the control groups used 'video only (no practice)', especially on day 1 ($p = .19$).

We also observed some large changes from day 1 to day 2 for some of the strategies. Almost 60% of control group participants (11 participants) used 'trial and error' on day 1, but only 6% (1 participant) on day 2 (a statistically significant change; Fisher's exact test $p = .001$). The change in use of 'practice without video' was not significant, however it is worth noting that more musicians used this strategy on day two (increase from 74% to 84%) while fewer control participants used this strategy on day 2 (decrease from 58% to 50%). 'Reviewing / slow practice' was not used much on day 1 (two participants from each group). On day 2, control participants did not use this strategy at all, but the number of musicians who used it increased to 5 participants (26%), although these changes in strategy use were non-significant.

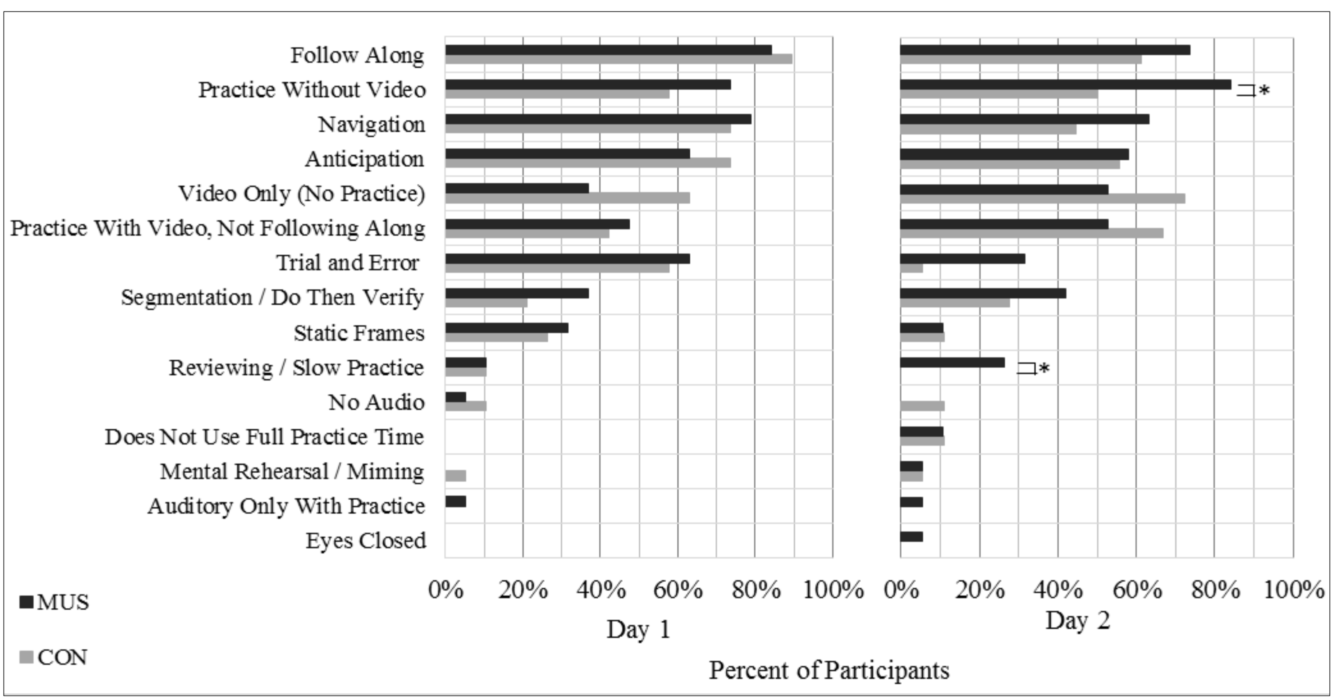

Figure 3: *Percentage of participants who use each particular strategy. Asterisks indicate significant difference (p < .05) between groups.*

Primary strategies
A primary strategy was identified as either the practice strategy that a participant used for the longest time or as the strategy that had the most distinct occurrences in the video. These strategies were assessed after labeling all strategies and the number of distinct occurrences of each strategy and the total time spent using each strategy were recorded. See Table 3 for a comparison groups in terms of which primary strategies were used.

There was no significant difference between groups in terms of the dominant practice strategies used; however, some noticeable differences are still worth noting. More musicians used "trial and error" as a primary practice strategy on day 1. The most common strategy used by both groups was "follow-along" on day 1 and "practice, no video" on day 2. By day 2, approximately two thirds of the musicians used a primary strategy that was not reliant on the video ('practice, no video' or 'practice with video, not following along'), compared to half of the control group. Finally, none of the musicians used "video only, no practice" as a dominant practice strategy. In comparison, 11% of control group participants used it as a dominant practice strategy on day 2.

Video navigation results/ Descriptive results
For each practice sessions, we extracted the number of pauses, total pause time, total playing time and number of replays (when a participant replays a section of the video that was already played). Results of a Mann-Whitney U test comparing the groups are shown in Table 4.
Musicians paused the video more times than control group participants on day 1. A majority of control participants (12 of the 19) did not pause at all, compared to 3 of the 19 musicians. The difference between the groups in terms of number of pauses was significant (p = .002). On both days, the control participants played the video for a longer period of time than the musicians (statistically significantly longer on day 2; p = .015).

Table 3. *Primary strategies used by each group. Values are the number of participants followed by the percentage (in parenthesis) within each group. P-values show the results of a Fisher's exact test.*

	Day 1			Day 2		
Dominant Practice Strategy	MUS	CON	*p*	MUS	CON	*p*
Follow Along	10 (53%)	12 (63%)	0.743	4 (21%)	4 (22%)	1.000
Trial and Error	7 (37%)	2 (11%)	0.124	1 (5%)	1 (6%)	1.000
Practice Without Video	-	1 (5%)	1.000	9 (47%)	6 (33%)	0.508
Practice With Video, Not Following Along	2 (11%)	2 (11%)	1.000	4 (21%)	3 (17%)	1.000
Anticipation	-	2 (11%)	0.486	1 (5%)	2 (11%)	0.604
Video Only (No Practice)	-	-	-	-	2 (11%)	0.230

Table 4. *Comparison of musicians' and control group participants' use of the instructional video in terms of the number of pauses and replays, and playing and pause time*

		Median				
Day	Parameter	MUS	CON	*U*	*Z*	*p*
Day 1	No. of pauses	2.0	0.0	78.5	-3.092	0.002
	No. of replays	2.5	2.0	170.5	-0.282	0.778
	Playing time (min)	6.0	7.9	117.5	-1.828	0.068
	Pause time (min)	4.0	2.1	288.5	-1.828	0.068
Day 2	No. of pauses	0.0	0.0	189.5	-0.352	0.725
	No. of replays	1.0	1.0	179	-0.593	0.553
	Playing time	4.2	6.0	110.5	-2.421	0.015
	Pause time	5.8	4.0	11.5	-2.421	0.015

Practice behaviors and performance scores
Analyses were done to examine the relationships between observed practice behaviors and performance achievement in the post-practice session tests. Those tests were evaluated in terms of time taken to perform the test, and an OSATS (Objective Structures Assessment of Technical Skills) score which is a composite of Likert scale items, each rated on a scale from 1 to 5. In part 1 of this study [8] we compared musicians and a control group in terms of these performance parameters.

Relationship between number of strategies used and performance scores
We explored the relationship between the number of strategies used by the participants and their test performance as indicated by test times and performance scores. Table 5 shows these results. There was not a strong relationship between the number of strategies used and the test times/scores. For the control group, associations were medium (r > .3) or very close to medium. For the musicians, the associations were small or negligible. For the control group, the associations were different depending on the day; on day 1, those who used more

strategies did better on the test and did the test in less time.
On day 2, the opposite occurred.

Table 5. *Pearson correlation coefficients for test times and scores versus number of strategies used.*

		Correlation between test times and number of strategies used		*Correlation between test scores and number of strategies used*	
		R	*p*	*r*	*p*
Day 1	MUS	-0.17	0.498	0.02	0.929
	CON	-0.30	0.227	0.36	0.131
Day 2	MUS	0.26	0.293	-0.12	0.613
	CON	0.44	0.080	-0.29	0.238

Table 6. *Comparison of primary practice strategies used by the fastest participants with the slowest participants. Values indicate the number of participants from each subgroup that use a particular practice strategy as their primary strategy.*

		MUS		*CON*	
Day	Primary Practice Strategy	Fastest Third	Slowest Third	Fastest Third	Slowest Third
Day 1	Follow Along	2	6	2	6
	Practice Without Video			1	
	Anticipation			1	
	Practice With Video, Not Following Along	1		2	
	Trial and Error	3			
Day 2	Follow Along		2		2
	Practice Without Video	4	2	4	1
	Anticipation				1
	Video Only (No Practice)				1
	Practice With Video, Not Following Along	2	1	2	
	Trial and Error		1		1

Relationship between primary practice strategies and performance scores

We examined the relationship between the strategies used and performance in terms of test times and scores. The participants were grouped into thirds according to their test time ranking and performance score ranking. Then, in the case of test times for example, the primary practice strategies used by the fastest third of participants were compared with the primary strategies used by the slowest third of participants. Each third consisted of 6 participants; for group sizes of 19 participants we compared the top six with the bottom six, leaving the middle group with seven participants. Tables 6 and 7 show the primary strategies used by each of these subgroups.

'Trial and error' was used as the primary strategy by most of the fastest and highest scoring musician participants on day 1. In contrast, the control participants rarely used 'trial and error' as a primary strategy. In most cases, more of the slowest and the lower scoring participants used 'follow along' as a primary strategy. By day 2, most of the faster and higher-scoring participants (from both groups) did not appear to use the video significantly, as the most common practice strategies were 'practice without video' and 'practice with video, not following along'.

Phases of learning

Reached rehearsal stage

We deemed that participants had reached rehearsal stage when they were demonstrating that they could do the task without consulting the video (video is off, or running in the background without the participant paying attention to it), and they had minimal mistakes and hesitations. See Table 8 and table 9 for a comparison of participants who reached rehearsal stage versus those who did not in terms of the number of participants and their test times and scores. The scores are composites of OSATS (Objective Structures Assessment of Technical Skills) Likert scale items (rated 1 to 5).

More musicians reached the rehearsal phase on both days. For both groups, those who reached the rehearsal phase seemed to perform the test better in terms of times and scores. There was a statistically significant difference found for the scores. For the test times, the difference was significant just for the control group on day 1, however for all other cases the same trend is evident.

Table 7. *Comparison of primary practice strategies used by the highest scoring participants with the lowest scoring. Values indicate the number of participants from each subgroup that use a particular practice strategy as their primary strategy.*

		MUS		*CON*	
Day	Primary Practice Strategy	Best Third	Worst Third	Best Third	Worst Third
Day 1	Follow Along	1	4	3	4
	Practice Without Video			1	
	Anticipation				1
	Practice With Video, Not Following Along		1	2	
	Trial and Error	5	1		1
Day 2	Follow Along	1	1	1	3
	Practice Without Video	2	4	2	1
	Anticipation			1	1
	Video Only (No Practice)				1
	Practice With Video, Not Following Along	3	1	2	
	Trial and Error				

Time-stamp quadrant

We identified when, during each of the 10 minutes practice sessions, each participant reached the rehearsal stage by dividing the practice time into four equal sections or quadrants. Each participant was then assigned as reaching the rehearsal stage in the 1st quadrant (0-2:30 min.); 2nd quadrant (2:31-5:00); 3rd quadrant (5:01-7:30); 4th quadrant (7:31-10:00); or as rehearsal not reached. This approach reduced the importance of defining a specific time when the rehearsal stage was reached. Table 10 shows the breakdown of participants according to when they reached rehearsal stage.

In general, the musicians reached rehearsal phase earlier in the practice session than control participants. On day 1, four musicians (22%) reached rehearsal phase in the first half of the practice session, compared with zero control group participants. For day 2, this comparison was 15 musicians (79%) versus 9 control group participants (50%).

Reached automaticity stage

We identified that participants had reached the automaticity stage when they were either 1) able to do the task very quickly and smoothly without hesitations; 2) tied many knots in a session (more than 20); 3) were practicing with the video off; or 4) showed signs of dual tasking, such as talking to the research assistant without interrupting the task, watching the video or looking elsewhere while continuing the task uninterrupted. See Table 11 for the percentage of participants who reached automaticity as well as how well they performed on the test (no statistical results are provided because of the small number of participants who reached automaticity). More musicians reached automaticity, and those who did also performed the test better in terms of times and scores.

Table 8. *Comparison of performance times of participants who reached rehearsal phase and those who did not. The "yes" columns refer to those participants who made it to the rehearsal phase. Results of an independent-samples t-test are shown when sample sizes are 7 or greater.*

		Percent (No. of Participants)		*Mean Time (s)*		*Standard Deviation (s)*		
Day	Group	Yes	No	Yes	No	Yes	No	t
Day 1	MUS	58% (11)	42% (8)	66.4	90.4	29.2	43.9	1.438
	CON	42% (8)	58% (11)	65.9	140.5	37.3	26.9	4.742**
Day 2	MUS	84% (16)	16% (3)	43.9	72.7	20.0	20.3	
	CON	61% (11)	39% (7)	58.0	90.2	37.2	33.0	1.84

**$p < .01$

Table 9. *Comparison of performance scores of participants who reached rehearsal phase and those who did not. The "yes" columns refer to those participants who made it to the rehearsal phase. Results of an independent-samples t-test are shown when sample sizes are 7 or greater.*

		Percent (No. of Participants)		*Mean score*		*Standard Deviation*		
Day	Group	Yes	No	Yes	No	Yes	No	t
Day 1	MUS	58% (11)	42% (8)	3.65	2.88	0.58	0.45	-3.157**
	CON	42% (8)	58% (11)	3.60	2.20	0.68	0.67	-4.475**
Day 2	MUS	84% (16)	16% (3)	3.95	3.67	0.30	0.61	
	CON	61% (11)	39% (7)	3.65	2.77	1.04	0.63	-2.270*

*p<.05, **p<.01

Table 10. *Time quadrant in which participants reached rehearsal stage. Values are the percentage followed by the number of participants (in parenthesis) within each group.*

	Day 1		*Day 2*	
Time quadrant	Musicians	Controls	Musicians	Controls
First (0:00-2:30)	11% (2)	0% (0)	32% (6)	11% (2)
Second (2:31-5:00)	11% (2)	0% (0)	47% (9)	39% (7)
Third (5:01-7:30)	21% (4)	37% (7)	5% (1)	11% (2)
Fourth (7:31-10:00)	16% (3)	5% (1)	0% (0)	0% (0)
Didn't reach rehearsal	42% (8)	58% (11)	16% (3)	39% (7)

Phases of learning and primary strategies used

We investigated for a relationship between whether or not a participant reached the rehearsal stage or the automaticity stage and the primary strategies used by each participant. Table 12 shows the primary strategy used by those who reached the rehearsal stage compared with those who did not and Table 13 shows the primary strategy used by those who reached the automaticity stage. Note that in Table 13 the results are shown only for day 2 as only one participant reached automaticity on day 1.

Table 11. *Number of participants who reached automaticity stage and comparison of their performance times and scores. The "yes" columns refers to those participants who reached automaticity.*

		Percent (No. of Participants)		*Mean Time (seconds)*		*Mean Score**	
Day	Group	Yes	No	Yes	No	Yes	No
Day 1	MUS	5% (1)	95% (18)	15.0	79.9	5.0	3.2
	CON	0% (0)	100% (19)	-	107.3	-	2.8
Day 2	MUS	32% (6)	68% (13)	35.8	54.3	4.1	3.8
	CON	6% (1)	94% (17)	22.0	72.3	5.0	3.2

*composite scores of OSATS (Objective Structures Assessment of Technical Skills) Likert scale items (rated 1 to 5)

Table 12. *Primary practice strategies used by the participants who made it to the rehearsal phase versus those who did not.*

Group	Day	Primary Practice Strategy	Reached Rehearsal Stage	Did Not Reach Rehearsal Stage
MUS	Day 1	Follow Along	3	7
		Practice With Video, Not Following Along	2	
		Trial and Error	6	1
	Day 2	Follow Along	3	1
		Practice Without Video	8	1
		Anticipation	1	
		Practice With Video, Not Following Along	4	
		Trial and Error		1
CON	Day 1	Follow Along	4	8
		Practice Without Video	1	
		Anticipation	1	1
		Practice With Video, Not Following Along	2	
		Trial and Error		2
	Day 2	Follow Along	1	3
		Practice Without Video	6	
		Anticipation	1	1
		Video Only (No Practice)		2
		Practice With Video, Not Following Along	2	1
		Trial and Error	1	

Table 13. *Primary practice strategies used by musician participants on day 2 who made it to the automaticity phase versus those who did not.*

Primary Practice Strategy	Reached Automaticity	Did Not Reach Automaticity
Follow Along		4
Practice Without Video	3	6
Anticipation	1	
Practice With Video, Not Following Along	2	2
Trial and Error		1

'Trial and error' was used as the primary strategy by more than half of the musician participants on day one who made it to the rehearsal phase. For both musicians and control participants, most of those who made it to the rehearsal phase did not use the video as a primary strategy, with most participants either using 'practice without video' or 'practice with video, not following along'. 'Follow along' was used by many of the participants who did not reach the rehearsal phase.

Four of the thirteen participants who did not reach automaticity continued to rely on the video as their dominant practice strategy (using 'follow along'). 5 of the 6 participants who reached automaticity used either 'practice without video' or 'practice with video, and not following along', indicating they did not rely on the video.

Discussion

This study explored the differences in practice strategies used by musicians and a control group in learning a basic surgical skill and whether their choice of practice strategies would relate to performance of the task or would be more effective reaching rehearsal or automaticity stages. There was evidence to suggest that musicians adopted different and more efficient practice strategies when learning to tie a surgical knot and progressed at a faster pace through the phases of learning. The data suggest that music experts have learned how to practice more efficiently and support the possibility of the transfer of these practice skills to learning a new task.

Manual dexterity (Question 1)

We expected musicians to score higher in tests that evaluate a subject's fine motor skills. Interestingly, there were no differences between the groups on any of the pegboard tests. This would indicate that the correlation observed between practice behaviors and performance scores, as well as between practice behaviors and learning stages, were unlikely to have resulted from any differences in manual dexterity difference between musicians and control participants. Expert musicians evidently show high levels of dexterity in the music domain, but this ability is very specific and may not be transferable to more general fine motor skill tasks, at least the tasks required by the pegboard tests. Therefore, based on the pegboard assessments, practice strategies might be a major factor affecting performance scores and learning stages.

However, we should consider the relevance of these dexterity tests for assessment of expert musicians as they were designed to assess the dexterity of manual workers on a production line, such as sewing machinists and in the manufacturing industry [44]. The ability to place pegs on a board might not be related with the ability to play the piano or with the skills for completing a surgical knot. Few manual dexterity assessment tests are available and these two were chosen because they are standard tests in research on manual dexterity. But to measure the manual dexterity of experts already performing high motor tasks in a specific domain, it might be necessary to design a manual dexterity test better adapted for complex and fine high level dexterity skills.

It should be noted that musicians performed significantly better in the hand-gesture test in both hands, and also exhibited significantly less difference between the dominant and non-dominant hands. It suggested that musicians had an advantage with motor sequences and this might have played a role in the achievement scores of participants and might have interacted with practice behaviors. Musicians in our study may have a superior ability to coordinate bimanual motor sequences involving multiple steps and this might have influenced their practice behaviour and improved their ability to adapt to the task.

Selection and application of practice strategies (Q-2)

Variability of practice strategy

We expected to see differences in the number of strategies adopted by musicians compared to control group. In experimental studies, varying the type of practice used by each of the participants during the study enhances learning [56-58] and helps with the transfer of motor skills, allowing people to more easily generate novel motor responses [59]. In music, it has been shown that participants using a greater number of practice strategies reach the higher performance scores [32,60]. Because the participants were all doing the same task for the entire practice sessions on both days, we know there was no task variability (i.e. going from one task to another), so any changes in the number of different practice strategies was best categorized as practice variability [61]. In our study, musicians and members of the control group used the same number of strategies on day 1, but on day 2, the number of strategies used by the control group decreased, such that the difference between groups on that day was very close to statistically significant.

Style of practice
When participants are struggling with part of a task, they adopt different approaches. Some prefer to go for external help and seek aid from the video immediately when they are having difficulty. They tend to favour "follow along" strategies, and may use a lot of video navigation or may watch the video without moving their hands or doing any segment of the task. Others are more self-reliant and tend to use "trial and error" several times until they solve their difficulty. They may go for long periods of time without consulting the video, and may not navigate the video very much. They are likely to use self-discovery or problem-solving strategies more often, attempting to reconstruct the task from memory instead of following along. Research has established that participants learning under problem-solving conditions are more successful at a new task and they require fewer trials and less time [9]. More musicians showed less dependency on the video model in our study. The comparison of video use showed that the musicians' video-playing time was less than that of the control group. By day 2, they tended to favour "practice, no video" or "practice, with video, not following-along", as opposed to "follow along" as a primary practice strategy. Finally, significantly more musicians used 'practice without video' (p = .038) and 'reviewing/slow practice (p = .046) on day 2.

Deliberate practice strategies
People learn best when they engage in deliberate practice. This means that they are rehearsing the parts that are difficult instead of doing what they already know [62]. For example, in an observational study of practice behaviors of high-school wind instrument players, deliberate selection of critical points of practice, and repetition of sub-sections of music were correlated with greater performance achievement [39]. Similarly, other studies have demonstrated that musicians learning a new piece and who locate and correct sources of errors [28] used more repetition behaviors [32], more segmentation [60], focused on trouble spots and played slowly [63] and received higher performance scores.

We observed that musicians tend to use strategies that could be associated with deliberate practice more frequently than the control group. These strategies include: 'navigation', 'trial and error', 'segmentation / do then verify' and 'reviewing / slow practice'. One of these strategies, 'trial and error' was also used as a primary strategy by more than a third of the musicians on day 1, and was associated with faster and better test performances on day 1. In contrast, 'follow along'; the lower-performing participants in both groups used a strategy not closely associated with deliberate practice approach, more frequently.

Practice behaviors and performance score (Q-3)
We expected to find positive correlations between the number of practice behaviors and the success at learning the task, and we expected musicians to select the types of practice strategies that contribute to better performance score. For the musicians, we did not find any association between the number of strategies used and the test performances in terms of time or score. For the control group, there was a moderate correlation; however, the association was reversed on day 2 (the use of a larger number of strategies was associated with a lower score and higher times). These correlations were not significant. We expected to find that those who used more strategies would perform better. It is possible that we do not see this because of the short practice time and the small amount of time it took some participants to reach a high level of proficiency at this task. Those who mastered the task may have realized they were successful at it, and thus did not need to experiment with other potential strategies to achieve proficiency. At that time they would likely be in rehearsal phase, simply repeating the task without having to consult the video or try other approaches to improve their ability.

Progressions through the different phases of learning (Q-4)
We expected to see musicians reaching the rehearsal phase and automaticity phase sooner based on our expectation that they would have different practice behaviors. Research demonstrates that the speed of movement of a task is an indicator of automaticity [64,65]. People who have learned the task better will move faster. We saw that more musicians than control participants achieved automaticity, and those who did performed the test in less time than those who did not. The same was true in reaching the rehearsal phase: more musicians reached rehearsal phase, they reached it earlier in the practice session, and they completed the test in less time than those who did not. In part 1 of this study [8], musicians' test scores showed that they completed the task faster and that was not result in any loss of accuracy [18], but rather an indication that they had mastered the task, since those who did the task at a faster rate also had better quality performance scores.

Automaticity and choice of practice behaviors (Q-5)
We expected to find positive correlations between certain types of practice and automaticity, and we expect musicians to select the types of practice strategies that contribute to automaticity. When investigating the relationship between practice behaviors and performance times and scores, we noted a positive relationship between performance achievement and 'trial and error' as a primary strategy (in the musician group), and a negative relationship between performance achievement and 'follow along' as a primary strategy (in both groups). On day 2, those who perform better were less reliant on the video, using 'practice without video', or 'practice with video, not following along'. Since all participants had the exact same tasks and amount of time of practice, our results show that the strategies employed during practice were most likely determinative of their performance achievement. In other words, the best-performing participants

essentially learned the task differently by adopting different practice strategies than others who did not do so well with the task.

Limitations

Our study observed differences in the practice behaviors of musicians and non-musicians, and musicians selected and applied what appeared to be more efficient practice strategies. However, we must consider the possibility that what we observed was not only caused by the fact that musicians were using better practice strategies and therefore obtained better performance scores, but also by the possibility that musicians brought better motor skills to the task. As a result, they progressed faster through the learning stages, which affected their use of practice behaviors.

Our study looked at skill acquisition only and not at long-term retention. It is possible that the type of practicing strategies that contribute to higher acquisition achievement might not have the same effect on retention. For examples, studies have shown that blocked practice contributes to superior performance during acquisition, but to inferior performance (when compared with random practice, for example) for long-term retention [66]. Further studies would be needed to better understand the effects that musicians' practice expertise on long-term retention of newly acquired motor skills.

It would have been preferred that the coding of the practice strategies was a blind process; however, since the two observers recognized some of the participants as musicians or non-musicians, they were told which group all participants belonged to for consistency purposes.

Finally, we felt that descriptive analyses were the most effective approach for this investigation, supported with statistical analysis. However, due to small sample sizes it was not possible to perform statistical analysis in some cases.

Conclusion

This study examined the practice behaviors of expert musicians and control participants learning a new motor skill – a surgical knot-tying task. This research has led to the identification of practice strategies associated with better motor skill acquisition. The relationships found between observed practice behaviors and performance achievement scores have important implications for: (1) determining which practice approaches and specific practice behaviors are the most effective for increasing motor skill performance achievement, and (2) identifying which specific practice behaviors are the best predictors of performance achievement. Improving our understanding of why "some individuals may attain highly fast and accurate performance, while others never progress beyond a novice level" [21] is crucial if we want to be able to optimize conditions of training, heighten the choice of practice strategies used, and promote automatic levels of processing. Our findings identified some important aspects of practice that differentiate more- and less-abled learners, and featured that musicians demonstrate a higher usage of beneficial strategies. More research examining relationships between specific practice strategies and performance achievement is necessary before recommendations for practical application can be made.

In medicine, extensive empirical studies have been conducted on the efficiency of learning techniques in the domain of knowledge acquisition [67]. However, these training recommendations cannot be generalized to skill learning. Comparable understanding of the best techniques for the acquisition of complex medical motor skills would be desirable. More research is needed before valuable conclusions about the efficiency of skill acquisition can lead to specific recommendations for medical motor skill training.

References

1. Krings T, Topper R, Foltys H, et al. Cortical activation patterns during complex motor tasks in piano players and control subjects: A functional magnetic resonance imaging study. *Neurosci Lett.* 2000: 278(3): 189-193.
2. McCaskie AW, Kenny DT, Deshmukh S. How can surgical training benefit from theories of skilled motor development, musical skill acquisition and performance psychology? *Med J Aust.* 2011: 194(9): 463-465.
3. Rui M, Lee JE, Vauthey JN, Conrad C. Enhancing surgical performance by adopting expert musicians' practice and performance strategies. *Surg.* 2018: 163(4): 894-900.
4. Huberman AM, Miles MB. The qualitative researcher's companion. London, ENG: Sage; 2002.
5. Hond P. The hippocratic overture. *Columbia Magazine*. 2015, Spring; 1-5. Available at: http://magazine.columbia.edu/features/spring-2015/hippocratic-overture
6. Hughes DT, Forest SJ, Foitl R, Chao E. Influence of medical students' past experiences and innate dexterity on suturing performance. *Am J Surg.* 2014: 208(2): 302-306.
7. Adams JA. Historical Review and Appraisal of Research on the Learning, Retention, and Transfer of Human Motor Skills. *Psychol Bull.* 1987: 10(1): 41-74.
8. Comeau G, Chen KC, Swirp M, et al. From music to medicine: Are pianists at an advantage when learning surgical skills? *Mus Med.* 2020, 12(1): 19-36.
9. Singer RN. Motor Skills and Learning Strategies. In: O'Neil HF, ed. Learning Strategies. New York, NY: Academic Press; 1978: 79-106.
10. Krampe R, Ericsson KA. Maintaining excellence: Deliberate practice and elite performance in younger and older pianists. *J Exp Psychol Gen.* 1996: 125(4): 331-359.
11. Duvivier RJ, van Dalen J, Muijtjens AM, Moulaert VRMP, van der Vleuten CPM, Scherpbier AJJA. The role of deliberate practice in the acquisition of clinical skills. *BMC Med Educ.* 2011: 11(1): 101.
12. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med.* 2004: 79(10): S70-S81.

13. Ericsson KA. Deliberate practice and acquisition of expert performance: A general overview. *Acad Emerg Med.* 2008: 15(11): 988-994.
14. Ericsson KA. Enhancing the development of professional performance: Implications from the study of deliberate practice. In: Ericsson KA ed. The development of professional expertise: Toward measurement of expert performance and design of optimal learning environments. New York, NY: Cambridge University Press: 2009: 405-431.
15. Pear TH. Professor Bartlett on skill. *Occup Psychol.* 1948: 22: 92-93.
16. Ackerman PL. Individual differences in skill learning: An integration of psychometric and information processing perspectives. *Psychol Bull.* 1987: 102(1): 3-27.
17. Ungerleider LG, Doyon J, Karni A. Imaging brain plasticity during motor skill learning. *Behav Neural Biol.* 2002: 78(3): 553-564.
18. Fitts PM, Posner MI. Human performance. Belmont, CA: Brooks/Cole Publishing Company; 1969.
19. Logan GD. Toward an instance theory of automatization. *Psychol Rev.* 1988: 95(4): 492-527.
20. Shiffrin RM, Schneider W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychol Rev*. 1977: 84(2): 127.
21. Ackerman PL. New Developments in Understanding Skilled Performance. *Curr Dir Psychol Sci.* 2007: 16(5): 235-239.
22. Spruit EN, Band GP, Hamming JF, Ridderinkhof KR. Optimal training design for procedural motor skills: a review and application to laparoscopic surgery. *Psychol Res.* 2014: 78(6): 878-891.
23. Gluck MA, Mercado E, Myers CE. Learning and Memory; From Brain to Behavior. New York, NY: Worth Publishers; 2013.
24. Bernstein N. The Co-ordination and Regulation of Movements. Oxford, ENG: Pergammon Press, 1967.
25. Lee TD, Swanson LR, Hall AL. What is repeated in a repetition? Effects of practice conditions on motor skill acquisition. *Phys Ther.* 1991: 71(2): 150-6.
26. Williamon A, Valentine E. Quantity and quality of musical practice as predictors of performance quality. *Br J Psychol.* 2000: 91(3): 353-376.
27. Miksza P. Relationships among achievement goal motivation, impulsivity, and the music practice of collegiate brass and woodwind players. *Psychol Mus*. 2011: 39(1): 50-67.
28. Duke RA, Simmons AL, Cash CD. It's not how much; it's how: Characteristics of practice behavior and retention of performance skills. *J Res Mus Ed.* 2009: 56(4): 310-321.
29. McPherson GE. From child to musician: Skill development during the beginning stages of learning an instrument. *Psych Mus* 2005: 33(1): 5-35.
30. Geringer JM, Kostka MJ. An analysis of practice room behavior of college music students. *Contributions to Mus Ed.* 1984: 1(11): 24-7.
31. Ginsborg J. Classical singers learning and memorising a new song: An observational study. *Psychol Mus* 2002: 30(1): 58-101.
32. Hallam S. The development of metacognition in musicians: Implications for education. Brit J Music Educ. 2001: 18(1): 27-39.
33. Maynard LM. The role of repetition in the practice sessions of artist teachers and their students. Bulletin of the Council for Research in Music Education. 2006: 1:61-72.
34. McPherson GE, Renwick JM. A longitudinal study of self-regulation in children's musical practice. *Mus Ed Res*. 2001: 3(2): 169-86.
35. Nielsen SG. Learning strategies in instrumental music practice. *Brit J Music Educ.* 1999: 16(3): 275-91.
36. Smith BP. The role of selected motivational beliefs in the process of collegiate instrumental music practice. PhD diss. 2002.
37. Killian JN, Henry ML. A comparison of successful and unsuccessful strategies in individual sight-singing preparation and performance. *J Res Mus Ed.* 2005: 53(1): 51-65.
38. Miksza P. Relationships among impulsiveness, locus of control, sex, and music practice. *J Res Mus Ed.* 2006: 54(4): 308-23.
39. Miksza P. Effective practice: An investigation of observed practice behaviors, self-reported practice habits, and the performance achievement of high school wind players. *J Res Mus Ed.* 2007: 55(4): 359-375.
40. Miksza, P. A review of research on practicing: Summary and synthesis of the extant research with implications for a new theoretical orientation. Bulletin of the Council for Research in Music Education. 2011: 190: 51-92.
41. Wulf G, Mornell A. Insights about practice from the perspective of motor learning: A review. Music Performance Research. 2008: 2: 1-25.
42. Bann S, Darzi A. Selection of individuals for training in surgery. Am J Surg. 2005:190(1): 98-102.
43. Lee JY, Kerbl DC, McDougall EM, Mucksavage P. Medical students pursuing surgical fields have no greater innate motor dexterity than those pursuing nonsurgical fields. *J Surg Educ*. 2012: 69(3): 360-3.
44. Masud D, Undre S, Darzi A. Using manual dexterity to predict the quality of the final product in the small bowel anastomosis after a period of training. *Am J Surg.* 2012 Jun: 203(6): 776-81.
45. Stefanidis D, Korndorffer Jr JR, Black FW, Dunne JB, Sierra R, Touchard CL, Rice DA, Markert RJ, Kastl PR, Scott DJ. Psychomotor testing predicts rate of skill acquisition for proficiency-based laparoscopic skills training. *Surg.* 2006: 140(2): 252-62.
46. Strenge H, Niederberger U, Seelhorst U. Correlation between tests of attention and performance on grooved and Purdue pegboards in normal subjects. *Percept Mot Skills*. 2002: 95(2): 507-14.
47. Van Herzeele I, O'donoghue KG, Aggarwal R, Vermassen F, Darzi A, Cheshire NJ. Visuospatial and psychomotor aptitude predicts endovascular performance of inexperienced individuals on a virtual reality simulator. *J Vasc Surg*. 2010: 51(4): 1035-42.
48. Causby R, Reed L, McDonnell M, Hillier S. Use of objective psychomotor tests in health professionals. *Percept Mot Skills.* 2014: 118(3): 765-804.
49. Orpet RE. Frostig movement skills test battery. Consulting Psychologists Press; 1972.
50. Bandura, A. Vicarious and self-reinforcement processes. In: Glaser R, Ed. The nature of reinforcement. New York, NY: Academic Press; 1971: 228-278.
51. Bandura A. Self-efficacy: Toward a unifying theory of behavioural change. *Psychol Rev*. 1977: 84: 191-215.
52. Wulf G, Shea CH. Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychon Bull Rev*. 2002: 9(2): 185-211.
53. Landers DM, Landers DM. Teacher versus peer models: Effects of model's presence and performance level on motor behavior. *J Mot Behav*. 1973: 5(3): 129-39.
54. Zimmerman BJ, Rosenthal TL. Conserving and retaining equalities and inequalities through observation and correction. *Dev Psychol*. 1974: 10(2): 260.
55. Knoblauch H, Schnettler B. Videography: Analysing video data as a 'focused' ethnographic and hermeneutical exercise. *Qual Res* 2012: 12(3): 334-356.
56. Boyce BA, Coker CA, Bunker LK. Implications for variability of practice from pedagogy and motor learning perspectives: finding a common ground. *Quest.* 2006: 58(3): 330-343.
57. Proteau L, Blandin Y, Alain C, Dorion A. The effects of the amount and variability of practice on the learning of a multi-segmented motor task. *Acta Psychol.* 1994: 85(1): 61-74.

58. Wulf G, Schmidt RA. Variability of practice and implicit motor learning. *J Exp Psychol Learn Mem Cogn*. 1997: 23(4): 987.
59. Catalano JF, Kleiner BM. Distant transfer in coincident timing as a function of variability of practice. *Perc Motor Skills*. 1984: 58(3): 851-856.
60. Rohwer D, Polk J. Practice behaviors of eighth-grade instrumental musicians. *JResearch in Mus Ed.* 2006: 54(4): 350-62.
61. Schmidt RA. A schema theory of discrete motor skill learning. *Psychol Rev*. 1975: 82: 225-260.
62. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev*. 1993: 100(3), 363.
63. Barry NH. A comparison of advanced student musicians' and professional musicians' practice attitudes and strategies. *Southeastern J of Mus Ed*. 1991: 3: 32-41.
64. Keele SW. Movement control in skilled motor performance. *Psychol bull.* 1968: 70(6): 387-403.
65. Logan GD. Automatic control: How experts act without thinking. *Psychol Rev*. 2018: 125(4): 453-485.
66. Healy AF, Clawson DM, McNamara DS, et al. The Long-Term Retention of Knowledge and Skills. *Psychol Learn Motiv.* 1993: 30: 135-64.
67. Dunlosky J, Rawson KA, Marsh EJ, Nathan MJ, Willingham DT. Improving students' learning with effective learning techniques. *Psychological Science in the Public Interest.* 2013: 14(1): 4-58.

Biographical Statements

Gilles Comeau is the director of the Piano Pedagogy Research Laboratory at the University of Ottawa. He conducts research on various aspects of music learning and teaching: transfer of motor skills, motor learning, music reading, motivation, piano-playing health injuries, video-mediated learning.

Jillian Beacon is a Ph.D. candidate in Human Kinetics at the University of Ottawa. She conducts research at the Piano Pedagogy Research Laboratory where she is completing her dissertation examining the impact of somatic training modalities on dynamic motor behaviour of pianists. Her research interests include motor-learning, musician injury prevention, chronic pain management, and sensorimotor practice strategies for musicians.

Erin Dempsey, doctoral candidate at the School of Human Kinetics of the University of Ottawa, has earned degrees in Piano Pedagogy (M.A.) from the University of Ottawa and Music (B.Mus) from Brock University. Specializing in music performance anxiety, her research explores the relationships between self-efficacy and anxiety in young musicians. She has written several scholarly research papers on performance anxiety and continues to conduct research exploring ways to help reduce performance anxiety in young musicians.

Mikael Swirp is a mechanical engineer, piano teacher and research coordinator at the University of Ottawa Piano Pedagogy Research Laboratory.

Fady Balaa received his Bachelor of Science degree at the University of Ottawa, his MD degree at the University of Western Ontario and his residency in General Surgery at the University of Ottawa, followed by two clinical fellowships focusing on surgery. Dr. Balaa has a keen interest in medical education and has completed a Master's degree in Medical Education through the Center for Medical Education at the University of Dundee.

Donald Russell has a PhD in Mechanical Engineering from the Massachusetts Institute of Technology and is a Professor in the Department of Mechanical and Aerospace Engineering at Carleton University where his research is focused on interaction between biomechanical and mechanical systems.

Kuan-chin Jean Chen obtained her ARCT (piano) Performers and Teachers certificates from the Royal Conservatory of Music and completed her medical training in family medicine and emergency medicine at the University of Western Ontario. She is currently an attending physician and assistant professor at The Ottawa Hospital/University of Ottawa.

Appendix A: Test descriptions and administrative procedures for pegboard and hand-gesture tests

Perdue pegboard	
Description: A neuropsychological test of manual dexterity and bimanual coordination. The board consists of two parallel rows of 25 holes each. Pins (pegs) are located in cups situated at the top of the board on the right and left side. Collars and washers occupy the two middle cups.	*Procedure:* In the first three subtests, the subject places as many pins as possible in the holes, first with the preferred hand, then with the non-preferred hand, and finally with both hands within a 30-second time period. In the fourth subtest, the subject uses both hands alternately to construct "assemblies", which consist of a pin, a washer, a collar, and another washer. The subject just completes as many assemblies as possible within one minute. Demonstration and practice are provided prior to each subtest. Data was collected on a single-trial administration.
Grooved pegboard	
Description: This manipulative dexterity test consists of a board with 25 holes with randomly positioned slots. Pegs with a key along one side must be rotated to match the hole before they can be inserted. All the pegs are the same, that is, with a round side and a square projection, and so do the holes in the boards. This test measures performance speed in a fine motor task for the dominant and non-dominant hand. It requires more complex visual-motor coordination than most pegboard tests.	*Procedure*: Participants are instructed to place all pegs into the 25 holes, picking up one peg at a time, and using just one hand. The key of the peg must be matched with the shape of the hole in the board so that the pegs can go into the holes. Participants must fill the top row completely, from left to right, then fill each row the same way.
Fist/Edge/Palm	
Description: This measure of unilateral coordination involves motor sequencing that consists of successively placing the hand on the table in three different positions: (a) a fist; (b) extended fingers with edge of hand resting on the table; and (c) palm resting flat on table.	*Procedure*: The examiner demonstrates and allows the subject a trial to ensure comprehension of the task. Correction is provided as necessary, but without using the verbal cues "fist," "edge," or "palm." The subject is then asked to perform the task, repeating the sequence as fast as he/she can until told to stop. Twenty seconds is allowed for each hand.

Appendix B
Description of practice strategies

1. Follow along- Participants follow the video closely, step-by-step, attempting to do the task at the same time as the model demonstration on the video. Follow along can be done from beginning to end, when the video continues playing without being paused or rewind, or it can be use temporarily for specific sub-segments of the task.
2. Trial and error- Participants attempt to do a step without consulting the video directly (may be off, or be playing in the background, but the video is not being consulted at that time). Participants try a sub-segment several times, two or more different ways, or they do a sub-segment, get it wrong, undo that step, and then try again.
3. Navigation- Participants use the mouse to restart the video at an earlier or later part. They may subsequently watch part of the video, or consult a static image.
4. Video only, no practice: Participants spend time watching and listening to the video without moving their hands or doing any segment of the task. They may either be holding the materials motionless during this time, or may have no contact at all with the material.
5. Practice, no video- Participants are practicing and the video is turned off.
6. Practice, with video, not following-along- Participants are practicing and the video is playing, but the sub-segments they are doing do not match the sub-segments that the video is playing. They may be ignoring the video, (it is playing in the background), or may be doing steps at their own pace but occasionally turn their attention to the video that has remained playing without attempting to catch up to or match the video.
7. Anticipation: Participants are following along with the video, but they attempt to do the sub-segments before they are demonstrated by the video. This can be done from beginning to end of the task, or can be done temporarily for a particular sub-segment.
8. Segmentation/repetition: Participant undo and repeats a specific sub-segment to practice it multiple times before going on to the next step.
9. Static images: Participants pause the video and use a still frame as reference, or they pause the video and navigate through multiple still panes.
10. No audio: Participants plays the video, but turns off the audio so they only see the movements but do not hear the instructions.
11. Auditory only with practice: Participants practice looking at their hands and listening to the audio while using other strategies (such as follow along), but rarely looks up at the screen.
12. Mental rehearsal/miming: Participants "acts out" one or more sub-segments with body movements (i.e. moving their hands in the air), but do not actually do anything with the materials. This may happen while watching the video or not.
13. Reviewing/slow practice: Participants appear to deliberately slow down toward the end of the practice session after demonstrating that they can do the task very fast with minimal mistakes earlier on.
14. Eyes closed: Participants do the task with their eyes closed.
15. Not using full practice time: it was noted when participants did not use their full practice time and chose to stand around or look at objects in the room instead of practice, however, this was not included in the final practice strategy tally.