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The Central Strategy of Music Practice: A Blow-by-Blow Account

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Abstract

Individual practice is a ubiquitous component in the development of expert music performance, and music pedagogues for centuries have offered prescriptions to aspiring musicians regarding effective music practice. These prescriptions are often characterized as practice strategies, yet they often fail to precisely convey the moment-to-moment process of skill learning, one that embodies iterative sequences of prediction (intention), performance, perception, and adaptation. There is as yet no systematic research that documents the behavior of artist-level performers engaged in successful individual practice. This study is a detailed analysis of individual practice of six artist-level trumpet players. Recordings were analyzed in detail to document how the artists allocated time, responded to discrepancies between intentions and outcomes, and organized practice activities to effect moment-to-moment changes in their playing. The results reveal that expert practice can be analyzed and described in terms of one central strategy: formulating vivid goals, performing, perceiving discrepancies between intentions and outcomes, and adapting subsequent performance trials to render momentary challenges surmountable. This is followed by iterations in which expert musicians adjust the parameters of each succeeding performance trial in ways that reduce the discrepancy between intentions and outcomes while maintaining a high percentage of successful performance trials.

Keywords

music, practice, expertise, strategy

Introduction

Expert musicians are capable of extraordinary artistic performances that are made possible in large part through thousands of hours of individual practice (Ericsson et al., 1993). As expert musicians work to develop and refine the sounds they produce, they adapt what they think and do to make undoable passages of music not only doable, but beautiful and highly reproducible.

Adaptation through iterative experiences is central to the development of all perceptual-motor skills, including music (Keogh, 1977). The features of adaptation emerge from processes that monitor the current state of the body, predict movement outcomes, and compare those predictions to the actual outcomes that result from movement (Wolpert & Ghahramani, 2000). In other words, adaptability is made possible by mechanisms that compare the intended outcomes with actual sensory feedback (Pasalar et al., 2006; Tseng et al., 2007), and the information gained from perceived discrepancies between what is intended or expected and what occurs guides learners'

subsequent actions (Chen-Harris et al., 2008; Flanagan & Wing, 1997; Shadmehr et al., 2010; Vaziri et al., 2006; Wagner & Smith, 2008). As various effectors are activated to accomplish behavioral goals, sensory feedback provides important data that pairs movements with outcomes (Diedrichsen et al., 2010).

But optimal learning is not simply the result of repeating successful movements. Rather, advantageous adaptation requires information gathered from the results of unsuccessful movements (i.e., movements that fail to accomplish intended goals) (Metcalfe, 2017). Reliable changes in actions that accomplish behavioral goals are the result of repeating successful trials *and* perceiving discrepancies between intentions and outcomes in unsuccessful trials (Ariani et al., 2020; Mawase et al., 2018; Toppino & Gerbier, 2014). Any useful calculation to improve future performance trials must account for how previous trials have failed (Diedrichsen, 2005; Seidler et al., 2013), suggesting that optimal practice necessarily consists of successful and unsuccessful attempts.

It is well understood that repetition is an essential component of skill learning in every domain. Strategic repetition leads to habit formation, the strengthening of associations between perceptions and actions. These learned associations in turn lead to automaticity (Lally et al., 2010), in that successful movement production requires increasingly less conscious attention. Cognitive resources once required to coordinate learned movements can be allocated to solve more complex problems, a process that is reflected in the efficient neural activity of experts (Bilalic, 2017).

Increased automaticity also allows for fast decision-making regarding action selection and movement guidance. Whereas nonexperts typically experience a decline in accuracy as the speed of movements increases and a decline in speed as accuracy increases, experts evince no such speed-accuracy trade-offs. Fitts and Posner (1967) explain this deviation from novice behavior as a reflection of automatization of complex skills. Actions and decisions that require high cognitive effort for nonexperts have, for experts, been stored as procedural memories that are retrieved quickly, accurately, and effectively, and often without conscious attention. Such intuitive expertise is often expressed as a set of "if-then" decisions made below conscious awareness in response to context-bound conditions (Sternberg et al., 2000). Within the domain of music practice, moment-to-moment responses to the sounds an expert musician produces during each trial reflect individual expertise and are responsible for the consistent, reliable movement sequences that produce advantageous outcomes; in this case, to reliably perform beautiful music.

Individual music practice is central to the lives of professional musicians and music students alike. Musicians at every skill level practice to develop and maintain technical and expressive fluency on their instrument or voice (Chaffin & Lisboa, 2008; Ericsson et al., 1993; How et al., 2021; Loimusalo & Huovinen, 2021; Miksza, 2011).

Previous research concerning music practice has revealed important relationships among the activities of practice, efficacy, and expertise (Barry, 1990, 1992; Bloom, 1982; Cahn, 2008; Cash, 2009; Chaffin et al., 2003; Chaffin & Imreh, 2001; Chaffin & Lisboa, 2008; Duke, Allen, et al., 2009; Duke, Simmons, et al., 2009; Geringer & Kostka, 1984; Henley, 2001; Killian & Henry, 2005; Loimusalo & Huovinen, 2021; Miklaszewski, 1989; Nielsen, 2001; Rosenthal, 1984; Sloboda et al., 1996). It seems clear that a constellation of thoughts and actions during practice lead to lasting refinements in motor control and sound production.

Research investigating individual music practice in varied skill domains has flourished in the past three decades (Miksza, 2011; How et al., 2021). Results reveal that experts maximize practice efficacy by systematically organizing activities to reach well-defined goals (Ericsson, 2009), a key feature of deliberate practice (Ericsson et al., 1993). Goal-oriented planning, strategic adaptation, and reflection are essential components of the self-regulatory behavior associated with effective practice (for a review, see Varela et al., 2016).

Repetition and strategic modification of problematic passages are typical features of music practice aimed at change-making. Research

exploring the role of repetition in skill learning (Ariani et al., 2020; Mawase et al., 2018; Toppino & Gerbier, 2014) has shown what many great pedagogues and artist-performers have reported for centuries: multiple performance trials of difficult musical tasks are needed to refine perceptions and actions. The individual practice of artist-level musicians shows an extensive and effective use of repetition to improve strength, flexibility, accuracy, fluency, and speed (Maynard, 2006).

Of course, multiple repetitions of a given movement are seldom identical, and the distinctive differences that emerge between consecutive repetitions serve to guide subsequent actions, both consciously and nonconsciously. Duke and colleagues (2009), in comparing the practice sessions of highly skilled pianists practicing a novel, challenging passage, found that those who learned most effectively performed a higher percentage of correct practice trials than did those who performed less successfully. The number of trials performed during practice was unrelated to levels of accomplishment; the percentage of trials played correctly was. This is reflective of how experts develop the habit of playing accurately and beautifully and learn efficiently and effectively: they tend not to repeat problematic passages without altering performance parameters in ways that increase the likelihood of success. This behavior may be explained as an effort to reduce the cognitive load associated with undoable tasks (Allingham & Wollner, 2022). Experts use strategic repetition with purposeful modifications to perform a high percentage of accurate trials.

The inaccurate trials performed during expert practice are also illuminating. Artist-level musicians, having accumulated thousands of hours of deliberate practice, would be expected to expertly perceive and reduce the frequency and magnitude of discrepancies between their intentions and outcomes. By repeating and modifying passages, expert musicians make small perceptual-motor adaptations that approach their artistic ideal. This is a primary mechanism through which their expertise has come to be.

Perhaps surprisingly then, there does not currently exist a detailed trial-by-trial analysis of expert practice that aims to explore how experts apportion time, make decisions, modify tasks, and respond to error during practice. The purpose of the present study was to describe in explicit detail and analyze the behavior of expert trumpet players engaged in individual practice. What may be described as a gap in the current music practice literature may be addressed, in part, by the novel method of analysis contained in this study.

What are believed to be the various elements of effective practice have been studied by researchers and shared by music teachers for many years. Many great musicians, teachers, and researchers have had much to offer to musicians who aspire to practice like experts (Barry, 1990, 1992; Cahn, 2008; Chaffin & Lisboa, 2008; Duke, Simmons, et al., 2009; Hallam, 2001; Henley, 2001; Killian & Henry, 2005; McPherson, 1997; Nielsen, 2001; O'Brien, 1943; Rosenthal, 1984; Ross, 1985; Suzuki & Suzuki, 1983). But the framework outlined in our data represents a departure from such prescriptions, asking instead how expert behavior reflects the strategic thinking and decision-making that affords artist-level musicians lasting refinements to procedural memories. Experts' effective practice is made possible by the iterative unfolding of prediction-action-perception loops that guide decision making in ways that render undoable challenges doable in the near term as they systematically approach the accomplishment of distal performance goals. The type of in-depth analysis of trial-to-trial behavior during practice and the inferred decision-making process operating concurrently had not yet been studied as parts of a whole.

To explore this, we asked the following questions:

- How do expert musicians allocate time, make moment-to-moment decisions, modify tasks, and respond to error during practice to produce consistently beautiful performances?
- Does the observable practice behavior of expert musicians constitute what we propose is a common central strategy that is employed in efforts to refine performance skills?

Method

Six artist-level trumpet players who have demonstrated extraordinary performance ability through sustained career success agreed to participate in this study: Chris Coletti, Justin Emerich, Gareth Flowers, Louis Hanzlik, Billy

Hunter, Jr., and Amy McCabe. A brief description of each artist's performance credential follows (for extended artist biographies, see Appendix A). The six participants were members of the extended professional network of the first author, who is an artist-level trumpet player as well as a teaching artist on the faculty of a university.

Participants

Chris Coletti is renowned as a trumpet soloist, for his work as principal trumpet of numerous top orchestras, as an arranger, and, famously, his ten years with the legendary Canadian Brass. Chris has performed and recorded with preeminent musicians and ensembles of our time, from Jon Batiste, Kanye West, and Quincy Jones, to the Metropolitan Opera Brass, the New York Philharmonic Brass, St. Louis Symphony, and conductors such as Pierre Boulez, Riccardo Muti, Michael Tilson Thomas, and Kurt Masur.

Justin Emerich is professor of trumpet at the Michigan State University College of Music. Emerich was acting associate principal trumpet of the San Francisco Symphony, and he has performed with the St Louis Symphony, Cleveland Orchestra, Metropolitan Opera Orchestra, San Diego Symphony, San Francisco Opera, Malaysia Philharmonic, Seoul Symphony, Seattle Symphony, Seattle Opera, Grant Park Symphony, New Jersey Symphony, Buffalo Philharmonic, Grand Rapids Symphony, Palm Beach Opera Orchestra, and the New World Symphony.

Gareth Flowers has been an associate musician at the Metropolitan Opera since 2014, and a member of the International Contemporary Ensemble since 2003. He has performed with the major orchestras of San Francisco, Seoul, Baltimore, Philadelphia, Washington, DC, and New York.

Louis Hanzlik is an internationally recognized, Grammy Award-winning trumpeter, chamber musician, and educator. A member of the renowned Orpheus Chamber Orchestra and American Brass Quintet (hailed by Newsweek as the "high priests of brass"), Hanzlik has performed throughout Asia, Australia, North America, South America, and Europe. He is a member of the faculties of the University of Connecticut, The Juilliard School, and the Aspen Music Festival.

Billy Hunter is currently principal trumpet with the Metropolitan Opera in New York and assistant principal trumpet with the Grant Park Symphony Orchestra in Chicago. Before this, he was principal with the New World Symphony and Spoleto Festival Italy orchestras and has performed as guest principal with the Frankfurt Radio Symphony in Germany, Malaysian Philharmonic in Kuala Lumpur, and the Charleston Symphony Orchestra. He has also performed with the New York Philharmonic, and the Boston, Baltimore, and Dallas Symphonies.

Amy McCabe is the principal trumpet player in the "President's Own" United States Marine Band, and has also performed with the New York Philharmonic, the National Symphony, The St. Louis Symphony, The Pittsburgh Symphony, The Brass Band of Battle Creek, the National Symphony Brass Quintet, and the Barclay Brass.

All artists were acquaintances of the first author, and all agreed to submit video recordings of one of their practice sessions and to have their identities disclosed. They received no compensation for their participation. The procedures were approved by the Institutional Review Board of The University of Texas at Austin.

Procedure

The authors contacted these six artists through email, requesting a video recording of their practice as it typically occurs. Specifically, we asked them to position the video camera so their head, instrument, and torso were visible, and to record a practice session during which they worked on repertoire they were preparing as part of their normal professional responsibilities. We asked them to "practice a passage of music that isn't where you want it to be. We are not looking for something that's at a particular state of readiness, just something that *you* think requires additional practice." The instructions go on to specify the following: "First identify a passage in your current repertoire or exercises to play. Then record a video of yourself playing that passage warts and all, followed by whatever you do next to get the passage closer to something you're satisfied with."

In soliciting the video recordings, we made no

specifications about the duration of the recording or the device used to record. Our only specification about the repertoire was that, at the time of recording, the piece not yet be performance-ready. We also asked that they not narrate their practice on the recording, but to practice as they typically would.

The six videos submitted by the participants show them working on different music, at different stages of the learning process, and solving differently perceived performance problems. Chris Coletti filmed himself in the early stages (in fact, his second practice session) learning a very small passage in one of the most difficult concerti in the trumpet repertoire, *Aerial,* by H. K. Gruber. Justin Emerich was preparing a trumpet excerpt from Igor Stravinsky's *Pulcinella Suite*. Gareth Flowers was learning a rhythmically and expressively complex unaccompanied solo by Mauricio Kagel, *Morceau de Concours.* Louis Hanzlik refined agogic accents and intonation while deciding on ornamentation in a transcription of a renaissance madrigal, *Sweet Honey-Sucking Bees,* by the English composer John Wilbye. Billy Hunter was in the early stages of learning a short, bluesy passage from Wynton Marsalis' *A Fiddler's Tale* to coordinate plunger technique. Amy McCabe was in the final stages of performance preparation, polishing a fast, technically demanding passage from the third movement of Ida Gotkovsky's *Concerto for Trumpet.*

We used *Scribe 5*[1] behavior analysis software (Duke, 2020) to code the video recordings with regard to episodes of playing (performance trials[2]), pauses between performance trials (intertrial intervals), and performance approximations that did not involve playing the trumpet (non-playing approximations[3]). All of these variables have been considered in much previous research on music practice (e.g., Duke et al., 2009; Maynard, 2006; Palese & Duke, 2022). We began by collecting numerical data to examine the allocation of time in each session: total session duration, number of performance trials, the duration of each segmented musical passage per performance trial, inter-trial time intervals, and observable non-playing approximations (i.e., singing, conducting through passages, or sub-vocalizing). We then created a highly detailed narrative analysis of one representative rehearsal frame from each recording (see Appendix B).

Results

The data appear in Table 1. Unsurprisingly, the number of performance trials generally increased in relation to the duration of the video; the rate of performance trials ranged from approximately 2.5 per minute to approximately 7 per minute. The overall mean performance trial duration was 5.8 seconds. Across all recordings, the mean proportion time spent playing the trumpet was approximately 57%. The duration of time spent in non-playing approximations varied widely from 0.0 seconds (Amy) to 272.9 seconds (Chris); five of the six participants devoted time to singing, conducting, or sub-vocalizing to approximate the target passage.

Table 1. Temporal Analysis of Artists' Allocation of Time

Participant	Video duration (min:sec)	Number of trials	Total trial duration (min:sec)	Percentage of video spent playing	Intertrial interval duration (in secs)		Performance trial duration (in secs)		Non-playing approximations	
					M	*SD*	*M*	*SD*	Episodes	Duration (in secs)
Chris	19:43	141	8:38	43.85	3.6	4.64	4.8	31.91	8	272.9
Justin	11:43	48	6:08	52.29	7.6	8.01	7.2	10.49	8	49.8
Gareth	10:52	28	6:48	62.47	14.5	23.77	8.7	13.03	9	84.8
Louis	9:01	33	5:01	55.68	9.1	9.49	6.9	13.88	9	43.7
Billy	7:15	38	5:14	72.71	8.2	9.72	3.0	6.13	12	33.8
Amy	4:01	23	2:17	57.83	5.9	5.59	4.1	9.07	0	0.0

Note. Performance trials are episodes of trumpet playing. Intertrial intervals are periods of elapsed time between performance trials. Non-playing approximations are observable attempts to perform one or more elements of the target passage away from the trumpet (e.g., singing, conducting).

Rehearsal Frame Analysis

Rehearsal frames are intervals of practice time devoted to the accomplishment of one or more specific goals in target passages (Duke, 1994, 2005). The rehearsal frame serves as an advantageous unit of analysis of teaching and learning, as it facilitates the observation of relationships between practice behavior and the target goals the behavior is intended to accomplish. After an analysis of time allocation, we identified the rehearsal frames in each recording.

This framework is also helpful in the analysis of individual practice, where a single musician is both teacher and learner (Maynard, 2006). Although individual musicians may begin practice with specific goals in mind, trial-to-trial outcomes inform practicers' moment-to-moment decisions as a practice session unfolds.

We identified the target goals and boundaries for each rehearsal frame based on observable features of the practice session. We based these decisions on (1) the passages of music the participants chose to perform for each trial (starting and stopping points), (2) modifications made to the music (e.g., changes to tempo, dynamics, articulation, pitches, number of notes performed), and (3) identifiable performance errors. Throughout all six recordings, the targets and rehearsal frame boundaries were clearly identifiable. (Recall that the first author is an artist-level trumpet player.)

The number of rehearsal frames in each recording varied from artist to artist. Amy's video (the shortest of the recordings) and Louis' video contain only two frames; the videos of Billy, Chris, and Justin each have six frames. The target of each rehearsal frame as well as the number of trials directed at achieving each target differs widely from artist to artist.

Of the rehearsal frames identified in each recording, we chose one representative rehearsal frame to analyze in great detail (see Appendix B). Chris' frame shows the tenacity and patience evident in the practice of experts when learning difficult music. Justin's frame shows how quickly and successfully experts recontextualize previously "doable-ized" material by adding features of the music that more closely resemble the intended performance of the entire passage. Gareth's frame shows the immediacy with which experts can transform undoable tasks into doable tasks. Louis' frame shows how experts doable-ize passages of music to refine expressive qualities of a performance (not just technical execution). Billy's frame shows him experimenting with movement solutions to approach his ideal inflection of a target passage. And finally, Amy's frame shows her confronting a common challenge in the practice of most trumpet players: a missed partial (when a player presses the correct fingering for a given pitch, while mistakenly sounding a different partial in the overtone series).

Throughout, there are consistent similarities in the practice observed. Each artist, guided by a detailed representation of how they intend to sound, identifies aspects of their performance that do not adequately align with that intent. This is typically followed by the immediate modification of the task at hand to allow them to reach proximal goals in the near term, which we refer to as doable-izing, and systemic recontextualization while maintaining performance quality. This is referred to as the *central strategy* below.

Rehearsal Frame Analysis, Chris Coletti

Table 2 (next page) presents the time allocation data from Chris's six rehearsal frames. Note that the target of Chris' sixth frame is to sing the passage as intended. Also note the short mean duration of trials in Frame 1 as Chris performed many iterations of a particularly difficult and short passage.

In Frame 1, the rehearsal frame selected for detailed analysis, Chris performs and sings (quite beautifully) with inflection. Even though he is in the very early stages of learning this difficult music, Chris' performance trials are being guided by an artistic ideal.

Chris typically stops immediately after errors, and repeats target passages (many times) where error occurs. He doable-izes by selecting smaller units (Trials 1-60), maintaining as much context as possible (i.e., the sequence of notes, tempo, articulation).

Chris takes time to think (1 minute, 34 seconds, 39.7% of the total frame duration). Not all performance trials are played on the instrument. This frame contains 2 episodes of non-playing approximations (happening between the trials analyzed above), for a total duration of 46.4 seconds (19.4% of the total frame duration).

The central strategy is observable in Chris' practice. First, the expressive inflection present in each trial reflects a detailed intention, even though he is in the early stages of preparation. Chris spends time formulating an idea for the sounds he intends to make (through beautiful vocalizing) and stops immediately after making sounds that deviate from that intention. He repeats target passages (in this case, quite small passages), and modifies difficult passages into doable versions of those passages while maintaining as much context as possible (he doable-izes). He also recontextualizes previously doable-ized passages, integrating successful refinements into performance trials that more closely resemble the final objective to perform the entire piece with technical and expressive fluency.

Table 2. Rehearsal Frame Targets and Time Allocation, Chris Coletti

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1*	Perform measures 71-72 with good tone, intonation, and clarity	3:57	0:04-4:01	61	2.5	2.4	46.4
2	Perform measures 73-74 with good tone, intonation, and clarity	0:48	4:02-4:50	14	2.8	1.5	0.0
3	Perform measure 73-74 with good tone, intonation, and clarity	2:08	5:08-7:16	24	3.7	1.6	1.8
4	Perform measures 71-74 with good tone, intonation, clarity on C trumpet	2:02	7:18-9:20	23	4.0	5.7	0.0
5	Recontextualize previously doable-ized material by performing on piccolo trumpet	2:29	9:36-12:05	13	7.5	8.6	0.0
6	Vocalize entire passage in time with accurate pitches and inflection	6:12	12:10-18:22	0	0.0	0.0	218.2

*Indicates rehearsal frame selected for detailed narrative analysis.

Rehearsal Frame Analysis, Justin Emerich

Table 3 (next page) presents the time allocation data from Justin's six rehearsal frames. Note that the target for Frame 2 contains only a single pitch yet is a necessary sub-goal for Justin to play the entire passage as intended. Also note that Justin recontextualizes in Frame 5 not by adding more notes, but by adding the regular time of a metronome.

In Frame 4, the rehearsal frame selected for detailed narrative analysis, Justin plays each trial with appropriate inflection (in this case, with the buoyancy and clarity that is stylistically typical of this passage). He stops immediately when errors occur in Trial 9. He repeats target passages where error occurs (e.g., measures 12, and 13). He doable-izes the entire passage into smaller segments (as in Trials 2-5, and 11), adjusts the time during performance trials (as in Trials 2-8, and 11), and slurs passages instead of tonguing them (as in Trials 4, 5, and 11) to focus attention on important sources of error. Once error is addressed it is typically absent from future trials.

Justin adds features that more closely resemble the intended performance of the final passage, to assess how previously refined passages function in a larger musical unit. He does this by adding more notes (as in Trials 6, 9, and 12), increasing the tempo (as in Trials 3, 7-9, and 12), and adding articulation back in (Trials 6, and 12).

Justin takes time to think in this frame (48.7 seconds, 40.7% of the total frame duration). This frame contains 1 episode of non-playing

approximation (happening between the trials analyzed above), for a total duration of 4.5 seconds (4.2% of the total frame duration).

The central strategy is observable in Justin's practice. First, the expressive inflection present in each trial reflects a detailed intention. Justin pauses to think between trials. He spends time formulating an idea for the sounds he intends to make, and stops immediately after making sounds that deviate from that intention. He repeats target passages and modifies difficult passages into doable versions of those passages while maintaining as much context as possible. He also recontextualizes previously doable-ized passages, integrating successful refinements into performance trials that more closely resemble the final objective to perform the entire piece with technical and expressive fluency.

Table 3. Rehearsal Frame Targets and Time Allocation, Justin Emerich

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1	Decide between single and double tonguing 16ths, articulate 16ths clearly, in-time	0:57	0:09-1:06	8	5.5	7.67	0.0
2	Perform a resonant low E	0:10	1:06-1:16	2	1.3	0.74	0.0
3	Clearly articulate 16th notes	0:45	1:16-2:01	7	2.7	0.84	9.2
4*	Perform melodic leap in tune with good tone (E-G#), clear/in-tune 16ths following large melodic leap	1:58	3:53-5:50	13	5.5	4.67	4.5
5	Contextualize previously doable-ized material by coordinating with metronome	3:29	6:44-10:13	7	14.7	8.58	7.8
6	Clearly articulate 16th notes	0:43	10:23-11:06	3	12.0	9.58	0.0

*Indicates rehearsal frame selected for detailed narrative analysis.

Rehearsal Frame Analysis, Gareth Flowers

Table 4 (next page) presents the time allocation data from Gareth's five rehearsal frames. Note that four of his five frames contained non-playing approximations. Also note that Frames 1 and 5 contained trials that were runs of long musical passages, leading to the highest mean trial durations for any rehearsal frames in the study.

In Frame 5, the rehearsal frame selected for detailed narrative analysis, Gareth plays each trial with inflection. He repeats target passages where errors occur (measures 91-93, and measures 96-99). He doable-izes the large passage played in Trial 1 by selecting a small segment for Trial 2, performing it much slower, immediately turning an undoable task into a performance trial with no identifiable error. He also stops immediately after an error occurs in Trial 4.

Gareth takes time to think between performance trials, (total inter-trial duration = 45.7 seconds, 20.7% of the frame duration) and has one episode of non-playing approximation (17.8 seconds, 8.1% of the frame duration).

The central strategy is observable in Gareth's practice. First, the expressive inflection present in each trial reflects a detailed intention. Gareth pauses to think between trials. He spends time formulating an idea for the sounds he intends to make, and he stops immediately after making sounds that deviate from that intention. He repeats target passages and modifies difficult passages into doable versions of those passages while maintaining as much context as possible.

Table 4. Rehearsal Frame Targets and Time Allocation, Gareth Flowers

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1	Perform big leaps with consistent resonance and pitch (8vb)	2:13	0:08-2:25	3	30.0	7.68	20.3
2	Perform 16ths with clarity and resonance	0:35	1:53-2:28	2	17.1	14.88	0.0
3	Perform big leaps with consistent resonance and pitch (in the printed octave)	0:55	2:50-3:45	3	13.0	5.57	8.4
4	Recontextualize previously doable-ized material, with extended techniques in correct octave	2:41	3:51-6:32	12	7.9	10.94	26.9
5*	Perform 16ths in measure 92-99 with resonance, clarity, and accuracy	3:42	7:10-10:52	8	22.1	38.92	17.8

*Indicates rehearsal frame selected for detailed narrative analysis.

Rehearsal Frame Analysis, Louis Hanzlik

Table 5 (next page) presents the time allocation data from Louis's two rehearsal frames. Note that both frames contain non-playing approximations. Also note that the targets for both frames are driven by expressive intent.

There are not many obvious instances of error in Frame 2, the rehearsal frame selected for detailed narrative analysis. Instead, Louis structures performance trials in response to discrepancies between his expressive intent and the sounds he produces. In other words, in this frame, errors are not missed notes, but rather sounds that do not align with Louis's expressive intent. As with the other experts in this study, each trial is performed with inflection.

Louis doable-izes to focus attention on important sources of discrepancy. He does so by segmenting smaller units (as in Trials 2-5). In Trial 5, he made a decision about the agogic accents in measure 26, (i.e., the execution matched with Louis' intent) and all future trials were consistently performed with the same inflection. This decision is followed by adding features that more closely resemble the intended performance of the final passage to assess how previously refined passages function in a larger musical unit. This is done by adding more notes (as in Trials 6, 10, and 11).

Louis takes time to think in this frame (total intertrial duration = 55.5 seconds, 40.0% of the total frame duration). Not all performance trials are played on the instrument. This frame contains 3 episodes of non-playing approximations, (happening between the trials analyzed above) for a total duration of 10.6 seconds (7.9% of the total frame duration).

The central strategy is observable in Louis' practice. First, the expressive inflection present in each trial reflects a detailed intention. Louis pauses to think between trials. He spends time formulating an idea for the sounds he intends to make and stops immediately after making sounds that deviate from that intention. He repeats target passages and modifies difficult passages into doable versions of those passages while maintaining as much context as possible. He also recontextualizes previously doable-ized passages, integrating successful refinements into performance trials that more closely resemble the final objective to perform the entire piece with technical and expressive fluency.

Table 5. Rehearsal Frame Targets and Time Allocation, Louis Hanzlik

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1	Perform measures 1-20, in time and in tune with the intended inflection and ornamentation	6:32	0:09-6:41	22	9.7	10.22	33.1
2*	Perform measures 20-27, in time and in tune with the intended inflection and ornamentation	2:20	6:41-9:01	11	7.8	7.68	10.6

*Indicates rehearsal frame selected for detailed narrative analysis.

Rehearsal Frame Analysis, Billy Hunter

Table 6 presents the time allocation data from Billy's six rehearsal frames. Note that the target of the first frame is explorative. Also note that the target of the fourth frame is to sing the passage as intended and consists only of sung trials away from the instrument.

In Frame 6, the rehearsal frame selected for detailed narrative analysis, Billy plays and sings each trial with inflection. In many trials (such as Trials 3-9) Billy is not eradicating obvious error. Instead, he is reducing a discrepancy between the expressive elements he intends to perform and the sounds coming out of the trumpet in each trial. He takes time to refine or clarify how he intends to perform. Prior to Trial 3, Billy vocalizes his intended inflection, which serves as a guide for the quick series of trials that follow.

Table 6. Rehearsal Frame Targets and Time Allocation, Billy Hunter

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1	Explore/experiment with how left-hand movement affects tone/intonation	1:54	0:03-1:57	8	11.6	10.80	1.9
2	Make a decision about which growl effect should begin the phrase	0:24	1:57-2:21	3	7.8	7.87	0.0
3	Coordinate left hand motion to make smooth melodic intervals	0:51	2:02-2:53	7	6.6	5.57	0.0
4	Vocalize intended inflection on pitch/in time	0:33	2:53-3:26	0	0.0	0.00	26.3
5	Coordinate left hand motion to perform intended inflection	0:45	3:29-4:14	2	19.5	4.56	0.0
6*	Coordinate left hand motion to perform smooth, resonant B-G interval	2:46	4:25-7:11	18	7.1	10.27	5.5

*Indicates rehearsal frame selected for detailed narrative analysis.

Billy repeats target passages (e.g., measure 21) where discrepancy occurs. He doable-izes into small units (sometimes just 1 or 2 notes, as in Trials 3-9, and 11-16), plays passages out of time (as in trials 3-9, and 11-15) to focus attention on important sources of discrepancy.

Following periods of doable-ization, Billy adds features that more closely resemble the intended performance of the final passage. This is done to assess how previously refined passages function in a larger musical unit. He does this by playing more notes (as in Trials 10, 17, and 18).

Not all performance trials are played on the instrument. This frame contains 2 episodes of non-playing approximations (happening between the trials analyzed above), for a total duration of 5.5 seconds (3.6% of the total frame duration).

The central strategy is observable in Billy's practice. First, the expressive inflection present in each trial reflects a detailed intention. This is perhaps most striking in the vocalizations, as Billy formulates a clear representation for the sounds he intends to make. He repeats target passages and modifies difficult passages into doable versions of those passages while maintaining as much context as possible.

Rehearsal Frame Analysis, Amy McCabe

Table 7 presents the time allocation data from Amy's two rehearsal frames. Note that the differences in mean performance trial durations between the two rehearsal frames is a result of the target goals in each frame. Note also that she did not perform any approximations away from the instrument.

Throughout Frame 1, the rehearsal frame selected for detailed narrative analysis, Amy plays each trial with inflection. Even Trial 9, which is played well below performance tempo, is still played with weighted agogic accents on each downbeat. She adjusts her movements to produce an artistic performance of this passage, not simply play the correct notes.

Amy also treats error in important ways. She stops immediately when errors occur in trials 3, 4, 8, and 15, and repeats target passages to address more precisely the source of error. Following the occurrence of an error, she doable-izes the appropriate passage. While maintaining time and character, she performs smaller units (as in Trials 4, 9, 10, 11, and 12) and slows the tempo (as in Trials 1, 4, 5, 9, 10-13, 16, and 17) to focus attention on important sources of error.

Following successful trials, Amy adds features of the music that more closely resemble the intended performance of the entire passage. This is done by adding more notes in succeeding trials (as in Trials 5, 6, 7, 9, 10, 14, 16, and 18), increasing the tempo (as in Trials 2, 6, 7, 10, 11, 12, 14, 17, and 18), and increasing the contrast between loud and soft dynamics (as in Trial 13). Amy makes quick decisions about what to play next. The mean duration of the interval between performance trials is 1 second.

The central strategy is observable in Amy's practice. First, the expressive inflection present in each trial reflects a detailed intention. She stops immediately to address error as she identifies discrepancies between her intent and the sounds produced. She modifies difficult passages into doable versions of those passages while maintaining as much context as possible, and she recontextualizes newly doable passages while playing many successful trials.

Table 7. Rehearsal Frame Targets and Time Allocation, Amy McCabe

Rehearsal frame	Target	Duration (min:sec)	Start - End times	*N* of trials	Trial duration (in secs)		Non-playing approximation (in secs)
					M	*SD*	
1*	Perform ascending triplets with no missed partials	1:36	0:34-2:10	18	4.2	2.67	0.0
2	Recontextualize previously doable-ized material, performing ascending triplets with no missed partials	0:43	3:14-3:57	3	12.1	7.01	0.0

*Indicates rehearsal frame selected for detailed narrative analysis.

Discussion

The common features observed in the practice recordings demonstrate that the expert musicians observed in this study maximize learning during practice by optimizing key features of perceptual-motor mechanisms responsible for updating procedural memory. The participants allocated resources in ways that would be expected of an individual who has refined movements through thousands of iterations of formulating intentions, performing, perceiving discrepancies between intentions and outcomes, and making decisions about how to reduce discrepancies in subsequent performance trials (Wolpert & Ghahramani, 2000; Wolpert & Landy, 2012). The elements of practice present in the recordings combine to form a procedure for skill refinement that is entirely consistent with the fundamental principles of procedural memory formation and the refinement of procedural memories over time (Schultz, 2017; Wolpert & Ghahramani, 2000).

Although the practice recordings varied in terms of their overall duration, the duration of target passages, the numbers and durations of performance trials and intertrial intervals, the modifications made during practice, and the participants' familiarity with the pieces performed, there were features of practice that were observed consistently among all the participants. This is not to say that all sessions were identical. Given the scope and nature of the individual participants' musical lives, their practice environments, and their specific goals, there were observable differences in how each musician behaved. Yet throughout, the foundational commonalities in expert behavior were striking. Combined, the following shared elements form an optimized constellation of behaviors during practice to effect reliable changes in perceptual-motor behavior. These are the observable features of expert practice that embody the central strategy of music practice.

Experts Formulate a Vivid Intention

A feedforward model of motor learning in music practice would predict that expert musicians develop detailed predictions for performance trials and consistently use an ideal representation to compare perceptual feedback with predicted feedback. The analyses of participants' practice indicate that their practice behavior is largely consistent with this expectation. We interpret the following as evidence that participants formulate and are guided by a detailed representation for how they intend each performance trial to sound and feel during practice.

First, participants spent considerable time performing approximations of the target passages away from the trumpet. The apparent goal of each iteration without the trumpet was to clarify the intent of the practiced passage. That participants devoted time (a commodity for these busy professionals) to this component of practice is consistent with the notion that optimal learning requires vivid predictions.

Second, the experts often stopped immediately when errors occurred. Although many musicians may take such an obvious behavior for granted, the immediacy with which experts stopped is important. These musicians did not need to stop and reflect to identify discrepancies. Rather, the discrepancies arose as instantaneous deviations *as the trial is performed*, which could only occur if being compared to a detailed prediction. In one exemplary series of performance trials, after a full run of an entire passage, Amy McCabe stops immediately when she perceives a discrepancy between what she intends to play, and the sounds produced during a series of performance trials (link to video). Discrepancies are surprising, likely slightly displeasing, and typically cue an immediate response to end a trial to locate the problem and address it.

And third, in line with the work of Hamilton and Duke (2020), the experts also appeared to spend time addressing quite subtle errors. Particularly in the practice of Billy, Louis, and Gareth, slight deviations of weight, dynamics, intonation, and tone appeared to cue subsequent modifications. Such subtleties could only be perceived in comparison to a clear and detailed representation of what was intended.

Experts Repeat Passages to Minimize Prediction Error

The experts in this study successfully modified the parameters of performance trials

in an effort to reduce discrepancies in subsequent performance trials. As suggested above, the participants' learning is guided by a high-fidelity auditory and proprioceptive representation that affords the ability to hear important and occasionally very subtle deviations from the ideal.

Following the immediate identification of discrepancies, the musicians optimally set boundaries around portions of the music to isolate and refine. They modified the task over several trials to reinforce effective motor updates in future trials. This cycle is integral to the optimal updating of the perceptual-motor system and most often requires multiple repetitions.

Predictably, the participants in this study performed many *modified* repetitions of passages in an effort to refine their performance. Multiple repetitions provide for exploration, experimentation, diagnosis of performance problems, and refinement. Most notable is the strategic modification of a given passage from one trial or set of trials to the next in ways that maintain a high percentage of accurate performances. In a collection of concentrated iterations, Justin Emerich performs a series of trials focused primarily on only two notes of the passage he was refining (link to video). By constraining the task, he is able to identify the problematic interval, and, within just a few trials, perform them resonantly, and recontextualize quickly. The participants consistently adjusted both the task parameters and the sounds produced to create adaptations that more closely approximated their ideal auditory and motor representation. When discrepancies were perceived, task demands were reduced in ways that facilitated future successful trials.

Experts Adjust Task Parameters Optimally (Doable-Ize)

Across all six recordings, participants rarely performed multiple consecutive unsuccessful trials of a problematic passage. When simple repetition of a passage proved an insufficient or inefficient path to improvement, the participants immediately employed modifications to the passage to facilitate motor updates. In other words, there are few instances of multiple unsuccessful repetitions. When participants recognize problems that require explicit attention, they immediately modify elements of the target passage to increase the likelihood of quality performance.

Although there is much research into the observable methods that musicians of varying ability use to modify tasks (Chaffin et al., 2003; Chaffin & Imreh, 2001; Miksza, 2007, 2011; Nielsen, 1999, 2001), almost every modification observed in the video excerpts can be characterized by a single common feature: they reduce the demands of the target task. Such alterations allow the practicer to achieve successful performance in a simpler task that approximates the final goal.

Once they decided how to reduce task demands, the experts in this study typically succeeded at the simplified task in one or two performance trials. Rather than continuing to repeat unsuccessful performance trials, the participants typically adjusted to perform successfully immediately, which facilitates learning in several ways. First, it increases the habit strength of successful execution. In addition, starting the refinement process from a place of reliability and stability (rather than inconsistency and fragility) affords the learner a successful starting point from which they can add complexity. The learner can structure the demands required for each performance trial to strategically modulate task difficulty, adding appropriate task demands to approximate the ideal performance of the problematic passage. This creates a sequence of performance trials that maintains performance objectives throughout more complex activities.

In one example, Billy Hunter plays one performance trial of a passage that he is unable to perform as he intends (link to video). This is followed by a series of 11 modified trials (three of which are sung). The modified trials are slower and contain fewer notes than the original passage, allowing him to allocate attention to the sources of the perceived discrepancies. Following the modified trials, Billy returns to the original passage with a successful trial.

Experts Maintain Optimal Context When Modifying Passages

Although they reduced task demands often when confronted with challenging passages, participants did not decontextualize passages any more than was necessary to make subsequent performance trials doable. They maintained contextual integrity by choosing elements of the selected passages that remained intact throughout practice. By maintaining the essential elements of a given physically challenging passage, participants increased the likelihood of successful transfer between practice and performance. For most performance trials, they retained important features of the passage while working on a proximal goal. Modified passages are altered only to the extent necessary to successfully accomplish target goals within several repetitions. In one illustration from the data, Gareth Flowers follows a problematic trial of a passage with two modified trials that afford him accuracy and expression with far fewer errors, while retaining time, rhythm, dynamics, and phrase shape (link to video).

Importantly, expressive elements were present in *every* performance trial observed in this study, suggesting the priority of expression in participants' thinking. Practicing the whole musical task appears to be the aim of much of the practice observed in this study. Maintaining the integrity of the musical activity enables learners to practice pairing perception and action as would happen in performance.

Experts Recontextualize Systematically

The participants recontextualized previously refined passages in systematic ways. Once a threshold for refinement of a modified passage had been met, participants situated the newly refined passage into a context that more closely resembled the final performance goal, but only to the extent that allowed them to perform successfully. This feature of expert practice likely contributes to their ability to maximize the rate of successful performance trials (Duke et al., 2009). Participants reduced the complexity of errorful tasks and maintained a high probability of successful performance by systematically adding complexity through recontextualization. In one illustration from the data, Louis Hanzlik identifies a small passage for refinement (presumably to add agogic accents to the penultimate bar of the phrase while maintaining phrase shape and intonation quality), refines the target passage, then recontextualizes in longer phrases that maintain the accuracy and expression he intends for that small passage (link to video).

Experts Make Decisions Quickly During Practice

Much of the intertrial time appears to show the musicians thinking. Taking time between performance trials facilitates detailed assessments of what just occurred and clear planning for upcoming performance trials. In one illustration from the data, Justin Emerich spent 26% of the video pausing to think between performance trials (we have edited these moments together sequentially into a compilation; link to video).

However, there are also many examples of expert thinking on relatively small timescales. Participants make very quick decisions between performance trials, often during pauses that are as brief as 1 second. Consider that in the process of practicing, musicians must make these decisions: When to stop; the location and nature of the most consequential discrepancy between what was played and what was intended; whether reducing the discrepancy requires modifications to one or more subsequent performance trials; what those modifications should entail; the start and end points of the succeeding performance trials; the criteria for determining whether or when to proceed in subsequent performance trials by repeating or recontextualizing the target passage.

The quick modification of problematic passages into doable passages was omnipresent in the practice recordings. This feature of expert practice is an important optimization that facilitates efficient, effective learning. As suggested earlier (Duke et al., 2009), a higher percentage of successful trials is associated with more effective learning. This would be the expected result as expert practicers develop habits of performance that lead to rewarding

outcomes. Experts make decisions to perform tasks that are successful most of the time.

As successful movements are automatized, cognitive resources once required to coordinate those movements can be allocated to solve more complex problems. This increases experts' capacity to make quick decisions about actions during practice. This would be expected as they avail speed-accuracy trade-offs by processing extensive perceptual data, comparing it with extensive accumulated procedural memory, and selecting optimal actions, fast. Experts do more with less (Bilalic, 2017).

As would be expected of perceptual motor experts in all domains, all the participants in this study make complex and precise decisions on a timescale that reflects their automatization of many of the processes engaged during music performance.

Conclusion

Like experts in all domains of perceptual-motor skill, the expert musicians we observed in the present study optimally refine the components of artistic music making through iterative experiences in which they do the following:

- Formulate a vivid intention/prediction for each trial
- Perform
- Identify discrepancies quickly
- Pause to think
- Strategically repeat passages to minimize prediction error by
    - adjusting the parameters of each succeeding performance trial to render momentary challenges surmountable in the near term
    - maintaining contextual elements to the extent possible
    - recontextualizing strategically in ways that maintain a high percentage of successful trials

This process is the primary framework through which all music learners develop increasing levels of strength, fluency, coordination, accuracy, and speed during effective practice. In fact, the list above may be considered the *central strategy of music practice*. What we refer to as the *central strategy* above is effective in improving music performance because it describes the fundamental principles of motor control responsible for all perceptual-motor skill development and refinement: iterative experiences predicting, acting, perceiving feedback, and adapting to minimize prediction error. This process underpins the extraordinary procedural memory refinement that characterizes expertise in the music practice observed.

Endnotes

1. Scribe 5 software allows observers to label video and audio recordings using behavior codes assigned by the user.
2. Intervals of time during which the participant played the trumpet, from the initiation of the first tone of a performance episode until the practicer removed the mouthpiece from the embouchure
3. Intervals of time during which the practicer performed the rhythmic or tonal elements of the piece in ways that did not include trumpet playing (e.g., singing, tapping)

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

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Appendix A: Artist biographies

Chris Coletti

Internationally acclaimed trumpeter Chris Coletti, best known for his work with the legendary Canadian Brass (2009-2019), is a soloist, chamber musician, orchestral musician and new Assistant Professor at Ithaca College School of Music. Comfortable in many musical styles, he has collaborated with a broad spectrum of musicians ranging from the Metropolitan Opera Brass, New York Philharmonic Principal Brass, Pierre Boulez, Michael Tilson Thomas and Ricardo Muti to Quincy Jones, Carlos Santana, Gloria Estefan and Miami Sound Machine. Chris also performs on the Baroque Trumpet with various early music ensembles in and around NY. Chris regularly performs with NOVUS NY, the all-star contemporary music orchestra of Trinity Church Wall Street in Manhattan.

Justin Emerich

A nationally renowned trumpeter and teacher with extensive national and international performing experience, Justin Emerich is associate professor of trumpet at the MSU College of Music. Emerich's orchestral experience includes serving as acting associate principal trumpet of the San Francisco Symphony, as well as performing with the St Louis Symphony, Cleveland Orchestra, Metropolitan Opera Orchestra, San Diego Symphony, San Francisco Opera, Malaysia Philharmonic, Seoul Symphony, Seattle Symphony, Seattle Opera, Grant Park Symphony, New Jersey Symphony, Buffalo Philharmonic, Grand Rapids Symphony, Palm Beach Opera Orchestra, and the New World Symphony. He has been a featured soloist with the Seattle Symphony and the Fulcrum Point New Music Ensemble in Chicago. In April 2013, Emerich was singled out as one of the San Francisco Symphony's "superb soloists" by the San Francisco Chronicle.

Emerich is also an avid chamber musician and has been a member of, and toured with, such groups as the Canadian Brass, Burning River Brass, Proteus 7, the Avatar Brass, and Pink Martini. Performing with these groups, he traveled extensively throughout Europe, Asia, the Caribbean, and all 50 states in the U.S. While with the world-famous Canadian Brass, he performed as solo-piccolo trumpet and collaborated with the New York Philharmonic and Philadelphia Orchestra brass sections. Emerich and the Canadian Brass were also featured with the New Jersey Symphony and premiered a new work by Bramwell Tovey with the Vancouver Symphony. He is currently the piccolo trumpet of Burning River Brass. Emerich performed in numerous Broadway shows in New York City including Kiss Me Kate, Into the Woods, and 42nd Street.

Gareth Flowers

Originally from Arlington, Virginia, Gareth Flowers is an electro-acoustic trumpeter, known for "shimmering vibrato" and "wide-ranging lines" (The New York Times, June 2010). He has performed with ICE since 2003. Although his musical journey has included performances with the major orchestras of New York, Philadelphia, San Francisco and Seoul, he relishes making music on an intimate scale, and performs with ICE, the TILT Creative Brass band, the Argento New Music Project, and the Tri-Centric Foundation's (Anthony Braxton) orchestra. He often performs in theatrical productions on Broadway, and has recorded for many fine musicians including Gabriel Kahane, Anthony Coleman, and duYun. As a composer-performer, he has had his own eccentric electro-acoustic Inventions performed at the Clark Studio Theater of Lincoln Center and at the Tank, and his electro-acoustic trumpet and laptop duo, the Batteries Duo, has performed at Issue Project Room, Bargemusic, and Cornelia Street Café.

Gareth received his Master of Music and Bachelor of Music degrees from the Juilliard School, where he studied with Raymond Mase and Mark Gould. He also recently joined the faculty of Columbia University's Music Department.

Louis Hanzlik

Louis Hanzlik was born in Iowa and is an internationally recognized trumpeter, chamber musician, and educator. As a member of the Grammy Award-winning Orpheus Chamber Orchestra and the American Brass Quintet, Hanzlik has performed concerts and presented solo and ensemble master classes in Asia, Australia, North America, South America, and Europe. He is associate professor of trumpet at the University of Connecticut, has been a member of the trumpet and chamber music faculties at Juilliard since 2014, and is also on the faculty at the Aspen Music Festival and School where he also serves as principal trumpet of the Aspen Chamber Symphony. As an educator Hanzlik promotes the inclusion of chamber music within a student's learning. His dissertation, Fostering Democracy and Citizenship through Chamber Music Coaching, from Teachers College Columbia University, examines chamber music's unique social and musical attributes. He has a bachelor's degree from the University of Iowa; a MM from Juilliard, and received his doctorate from Teachers College, Columbia University.

Billy Hunter, Jr.

A native of Austin, Texas, Billy Hunter is currently Principal Trumpet with the Metropolitan Opera in New York and Assistant Principal Trumpet with the Grant Park Symphony Orchestra in Chicago. Before this, he was Principal with the New World Symphony and Spoleto Festival Italy orchestras and has performed as Guest Principal with the Frankfurt Radio Symphony in Germany, Malaysian Philharmonic in Kuala Lumpur, and the Charleston Symphony Orchestra. Other orchestras he has performed with are the New York Philharmonic, Boston, Baltimore, and Dallas Symphonies. As a chamber musician and soloist Mr. Hunter has performed with several ensembles and music festivals including Grant Park Orchestra, New World Symphony, University of Texas Symphony and Wind Ensemble, Prometheus Chamber Orchestra, Eastern Music Festival Orchestra, American Brass Quintet, the Martha's Vineyard Chamber Music Festival and the MET Chamber Ensemble. His honors and awards include first prize in the Kingsville International Solo Competition Brass and Non-string divisions, second prize in the National Trumpet Competition, recipient of the Roger Voisin Trumpet award as a fellow of the prestigious Tanglewood Music Center in the Berkshires, and most recently, the University of Texas at Austin Outstanding Young Alumnus Award. A graduate of the University of Texas at Austin and the Juilliard School, his teachers have included Mark Gould (former Principal Trumpet of the Met), Raymond Mase (Principal Trumpet of the NYC Ballet and ABQ), Raymond Crisara (former trumpet of the Met and NBC Symphony), and Harry Shapiro (former horn player of the Boston Symphony).

Amy McCabe

Amy McCabe, a resident of Washington D.C., has performed on her trumpet in a variety of genres across the globe. Amy is currently principal trumpeter in a premier military band which performs regularly at the White House and on national concert tours. She was recently a featured solo recitalist at the International Trumpet Guild conference, the International Women's Brass Conference, a chamber recitalist at the Midwest Band and Orchestra Clinic and was a featured soloist with the National Youth Brass Band of Great Britain. In addition, Amy has also performed with the New York Philharmonic, the National Symphony, Brass Band of Battle Creek, the Monarch Brass and was a featured soloist of the first National touring cast of the Tony and Emmy-award winning show, Blast! Amy has been a member of the Chicago Civic Orchestra, a fellow at the Tanglewood Music Festival, Spoleto Music Festival, Pine Mountain Music Festival, Artosphere Festival and was a member of the Walt Disney World Collegiate All-Star Big Band. She holds a degree in elementary education from Illinois Wesleyan University studying with Steve Eggleston and Judith Saxton, and a master's degree in trumpet performance from Northwestern University, studying with Barbara Butler and Charles Geyer.

Appendix B: In-depth Performance Trial Analysis

Chris Coletti

The following analysis is from Chris' first rehearsal frame where he is practicing the passage shown in Figure 1: Measures 71-73 from H.K Gruber's trumpet concerto, *Aerial*. In the figures that follow, the portions of the passage that are performed in each rehearsal frame are passages of notation not grayed-out. We numbered the measures of this passage as shown in this figure.

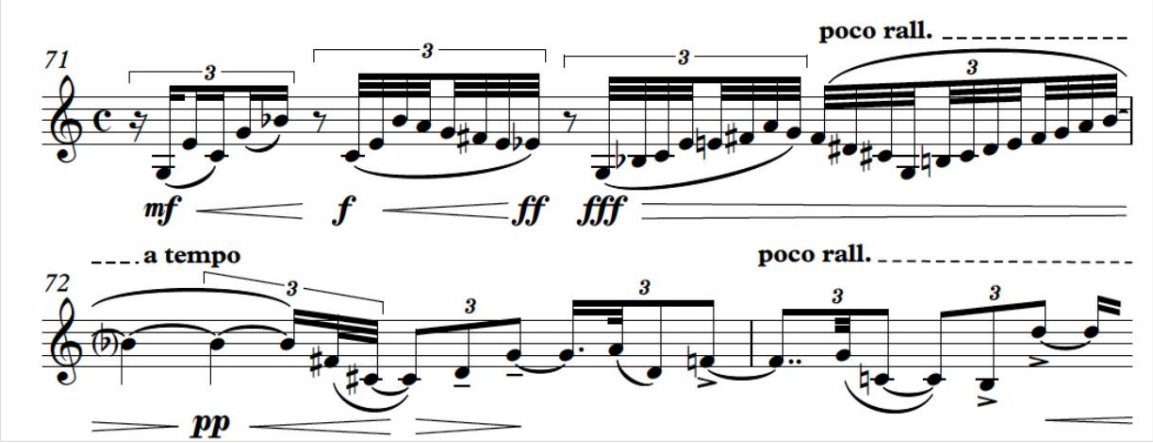

Figure 1. Chris Coletti Rehearsal Frame Notation, Gruber's *Aerial*

The rehearsal frame occurs between 0:04-4:01 in the excerpt and contains 61 performance trials (M = 2.4 seconds, SD = 2.39). Time prior to this frame was spent setting up and preparing to practice. Performance trials make up 2 minutes, 34 seconds of the rehearsal frame and non-playing approximations make up 46.4s. All trials in this frame are performed with the metronome sounding, but occasionally Chris plays trials out of time. This frame contains many trials with fingering coordination errors (the outcome of which is uneven rhythms), and unevenness in resonance and intonation. Chris' unfamiliarity with this difficult piece (this excerpt is one his first practice sessions) helps contextualize the preponderance of errors. This frame was chosen as an exemplar of the tenacity and patience evident in the practice of experts.

Chris Coletti Trial 1

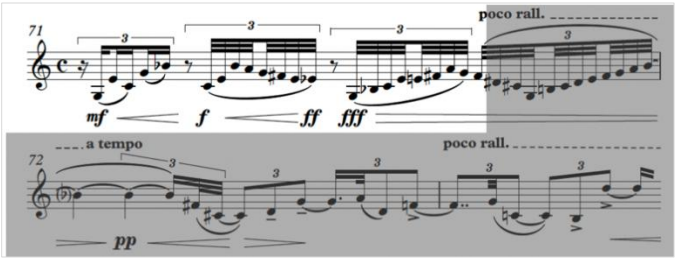

Figure 2: Chris Coletti Trial 1 Notation

Measure 71, beats 1-3, played at tempo. Uneven rhythm in descending line in beat 2. Chris ends trial immediately.

Chris Coletti Trial 2

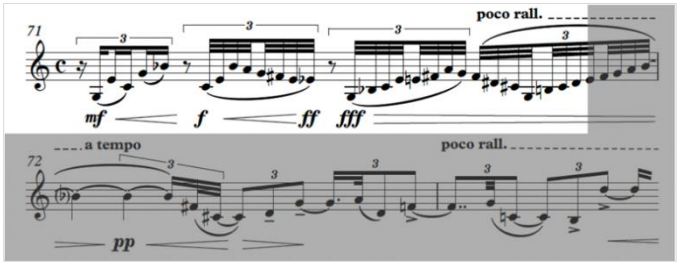

Figure 3: Chris Coletti Trial 2 Notation

Most of measure 71, with last note sustained. Uneven rhythm, resonance, intonation in beats 3 and 4. Chris ends trial immediately.

Chris Coletti Trials 3-52

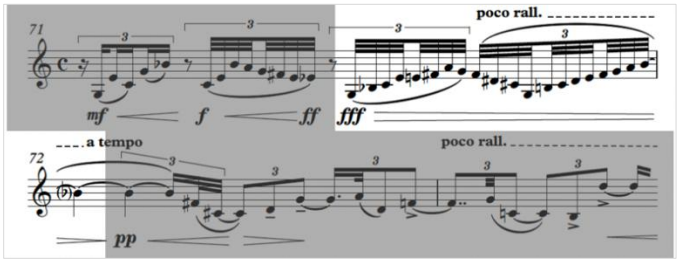

Figure 4: Chris Coletti Trials 3-52 Notation

Measure 71, beats 3, 4. Many short trials segmented in a variety of ways. Trials 49-52 add varied articulation (instead of the printed slurs). Some observable error in almost every trial (fingering coordination, uneven resonance, uneven intonation). Between Trials 6 and 7, Chris sings the pitches in beat 3. Following Trial 52, Chris spends 45 seconds without playing the trumpet, fingering through various patterns from measure 71.

Chris Coletti Trials 53-58

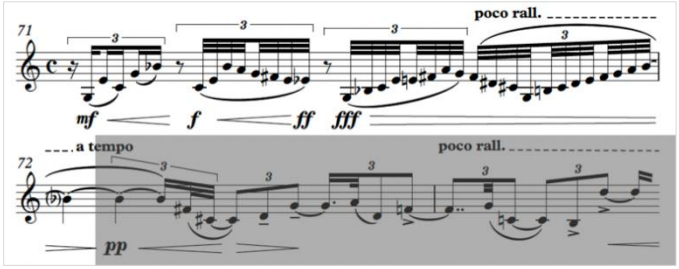

Figure 5: Chris Coletti Trials 53-58 Notation

Measure 71. Short trials segmented in a variety of ways. Some observable error in every trial (fingering coordination, uneven resonance, uneven intonation).

Chris Coletti Trial 59

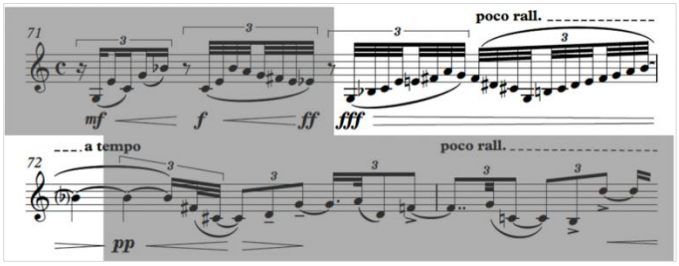

Figure 6: Chris Coletti Trial 59 Notation

Beats 3 and 4 of measure 71, performed for the first time in this frame with the first note of beat 4 articulated (as marked). Fluidity, resonance, and intonation improve. Following the trial, Chris can be heard saying "Oh, that helps."

Chris Coletti Trial 60

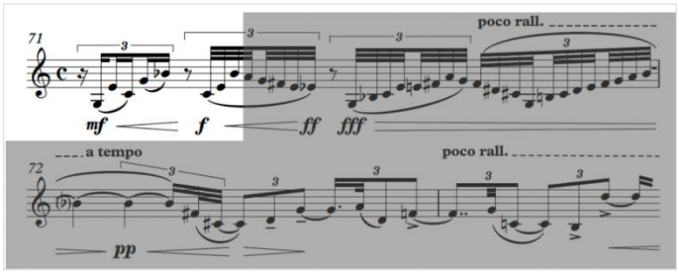

Figure 7: Chris Coletti Trial 60 Notation

The first 8 notes of the passage, but the last note does not sound. Chris ends trial immediately.

Chris Coletti Trial 61

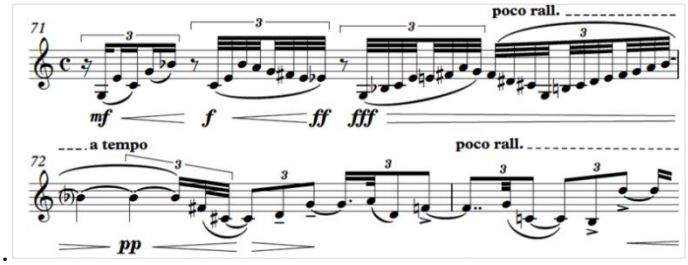

Figure 8: Chris Coletti Trial 61 Notation

The entire selected passage, played with resonance, dynamic contrast and inflection. There is one slight instance of uneven resonance in beat 4 of measure 71. Many of the previous identifiable errors are not present.

Justin Emerich

The following analysis is from Justin's fourth rehearsal frame in which he is practicing the passage, shown in Figure 9, from the fifth movement of Igor Stravinsky's *Pulcinella Suite*. We numbered the measures of this passage as shown in this figure.

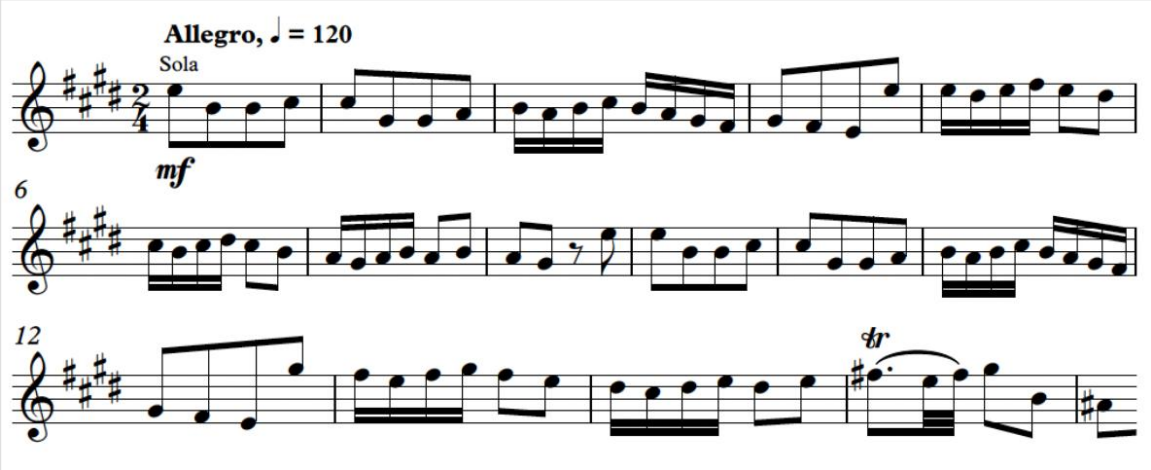

Figure 9: Justin Emerich Rehearsal Frame Notation, Stravinsky's *Pulcinella Suite*

This frame occurs between 3:53-5:50 and contains 13 performance trials ($M = 5.5$ seconds, $SD = 4.67$). Prior to this frame, Justin identified and addressed three smaller subgoals related to articulation clarity. Performance trials make up 1 minute, 12 seconds of the rehearsal frame and non-playing approximations make up 4.5 seconds. This frame contains instances of variable intonation and resonance of the tones surrounding the large melodic leap in the 12th measure (a major tenth, an uncharacteristically large leap in the orchestral trumpet repertoire). The refinement in this frame is likely directed at multiple sub-goals related to specific features of the performance trial such as articulation (i.e., the shape and clarity of initiated tone), resonance, and intonation that typically increase in variability as melodic interval size increases. The frame ends with two nearly identical trials of the problematic section, both of which are successful trials. This frame was chosen as an exemplar of how quickly artist-level musicians successfully incorporate doable-ized passages into context.

Justin Emerich Trial 1

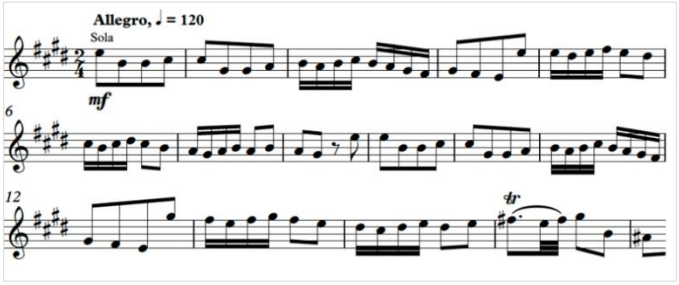

Figure 10: Justin Emerich Trial 1 Notation

The entire passage, played at tempo with no observable modifications (with a few off-task notes at the end of the trial). Following the large leap in measure 12, there are instances of uneven resonance, intonation, and articulation.

Justin Emerich Trial 2

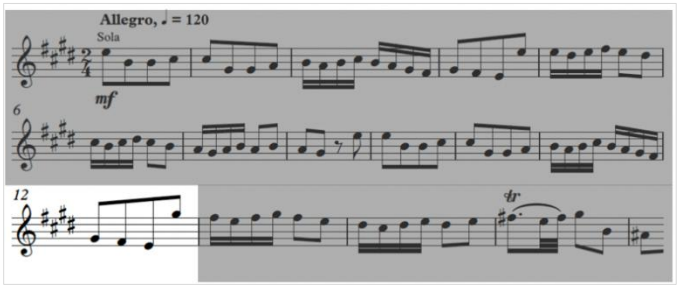

Figure 11: Justin Emerich Trial 2 Notation

A few repeated pitches performed prior to a trial of measure 12, consisting of only four eighth notes, played slower, with the last note of the bar held slightly longer than written. The notes surrounding the large leap are clear and resonant.

Justin Emerich Trial 3

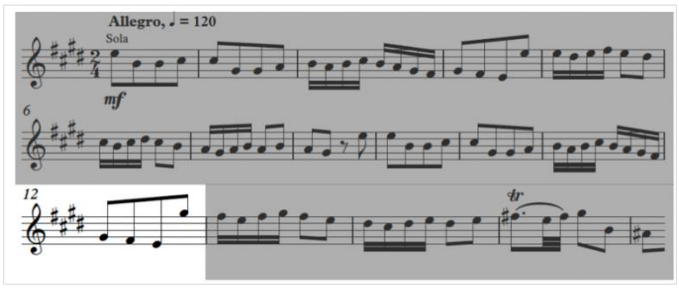

Figure 12: Justin Emerich Trial 3 Notation

The same measure as Trial 2, without the preceding repeated notes, slightly more in time. No identifiable errors occur.

Justin Emerich Trials 4, 5

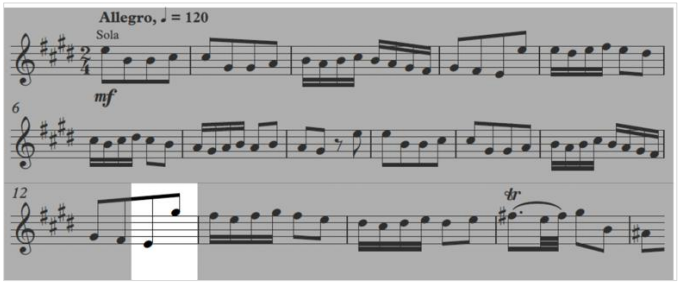

Figure 13: Justin Emerich Trials 4,5 Notation

Two pitches from measure 12, E-G# (played on Emerich's D trumpet, as D-F#), both of them elongated and connected by an extended glissando. Trial is resonant throughout.

Justin Emerich Trial 6

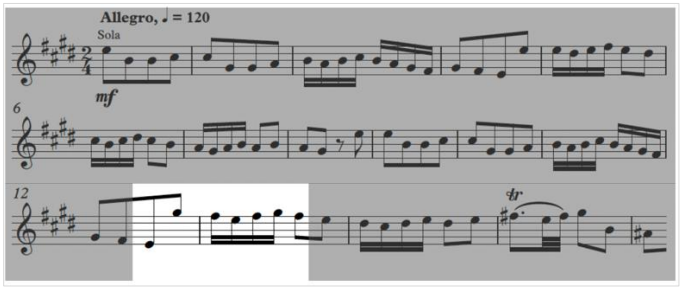

Figure 14: Justin Emerich Trial 6 Notation

The problematic interval is followed by the next five notes, and rhythmic relationships are restored. Tempo is still slow, and articulation is added back in. No identifiable errors occur.

Justin Emerich Trials 7, 8

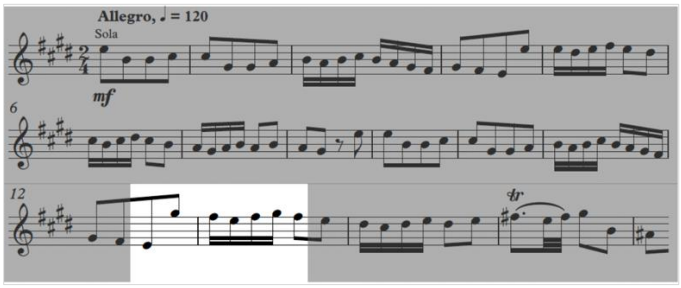

Figure 15: Justin Emerich Trials 7,8 Notation

Two trials consisting of the same seven notes played in trial 6 at almost the same tempo. Different fingerings used for printed F#'s vary the pitch (when played with valves 1-2, the pitch is sharp, when played in the open position, pitch is more in-tune). Future trials only use the open fingering for the F#.

Justin Emerich Trial 9

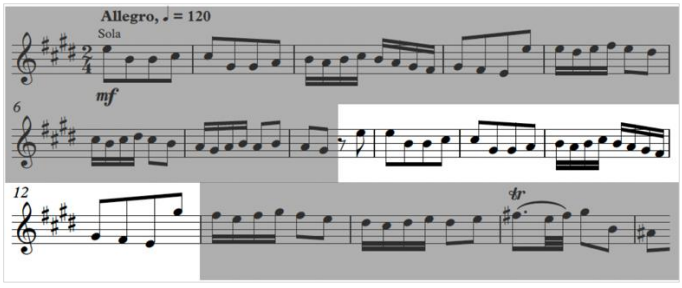

Figure 16: Justin Emerich Trial 9 Notation

From the pickup to measure 9 until an error occurs at the problematic major 10th four bars later. Justin ends the trial immediately.

Justin Emerich Trial 10

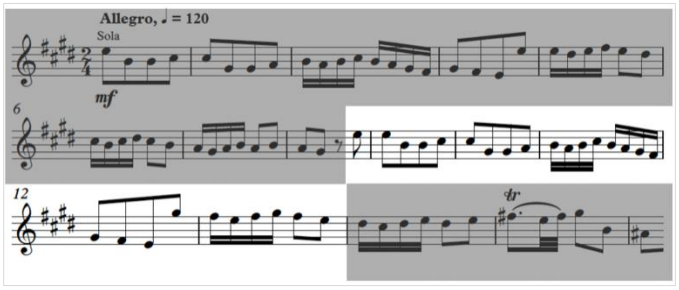

Figure 17: Justin Emerich Trial 10 Notation

From the pick-up to measure 9 until the series of notes in measure 13 are played without optimal resonance and response.

Justin Emerich Trial 11

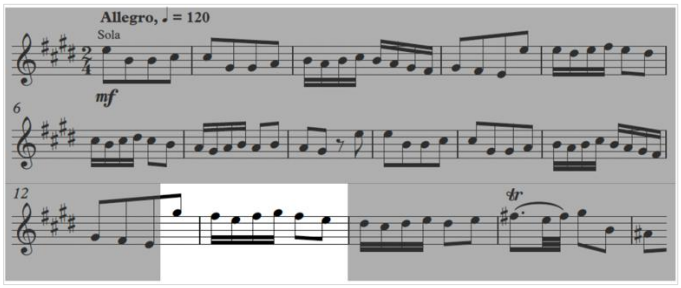

Figure 18: Justin Emerich Trial 11 Notation

Measure 13 with a pick-up note prior, mostly slurred (instead of articulated as marked) elongating the last four notes of the figure. No identifiable errors.

Justin Emerich Trials 12,13

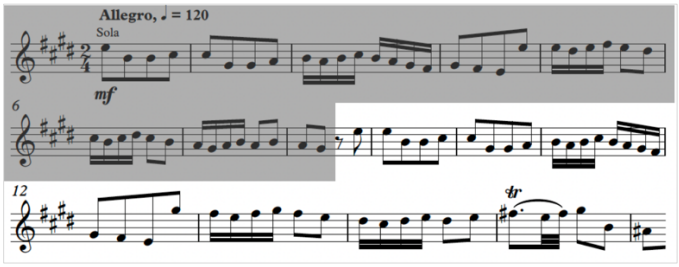

Figure 19: Justin Emerich Trials 12,13 Notation

Pick-ups to measure 9 with a pick-up, at tempo, with printed articulation. Performed with clear articulation and consistent resonance.

Gareth Flowers

The following analysis is from Gareth's fifth rehearsal frame where he is practicing the passage shown in Figure 20: Measures 91-99 from Mauricio Kagel's work for solo trumpet, *Morceau de Concours*.

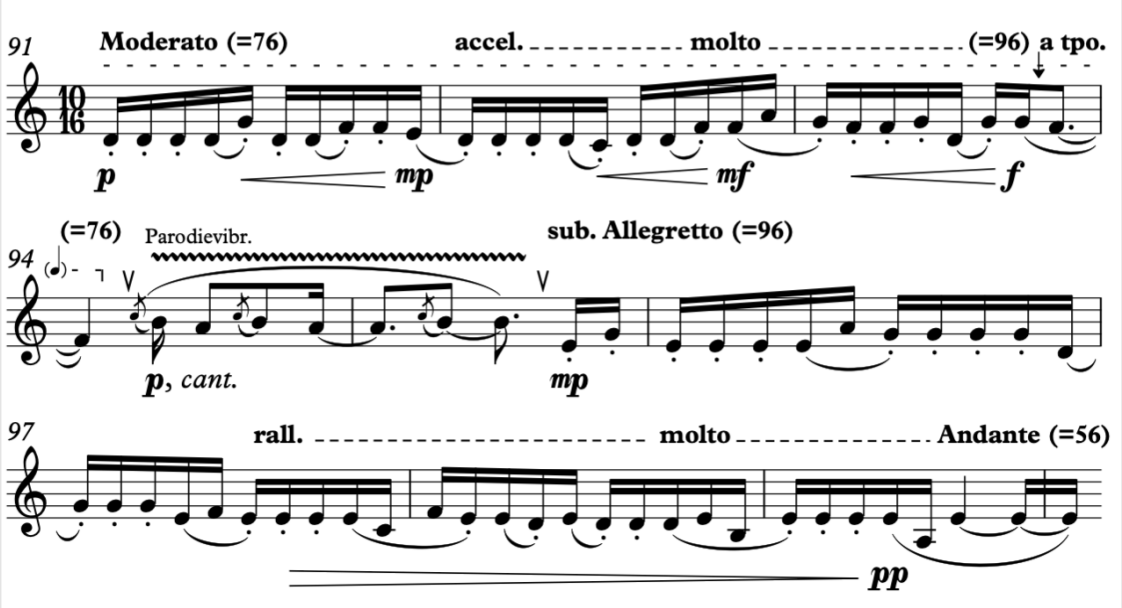

Figure 20: Gareth Flowers Rehearsal Frame Notation, Kagel's *Morceau de Concours*

The rehearsal frame occurs between 7:10-10:52 in the excerpt and contains 8 performance trials ($M = 22.1$ seconds, $SD = 38.92$). Prior to this frame, Gareth spent time on an earlier passage in the piece. Performance trials make up 2 minutes, 58 seconds of the rehearsal frame and non-playing approximations make up 17.8 seconds. The frame contains instances of Gareth refining the resonance and timing of the quintuplet sixteenth notes in measures 91-93 and 96-99, while maintaining the printed (and rhythmically unintuitive) articulation patterns. This frame was chosen as an exemplar of how quickly artist-level musicians modify difficult tasks into doable tasks.

In this frame, tempo modifications play a key role in how Gareth responds to the relative success of previous performance trials. To reflect this, the analysis below measures tempo from trial to trial in beats per minute (bpm). The peformance tempi marked in the score are used as the presumptive target performance tempi.

Gareth Flowers Trial 1

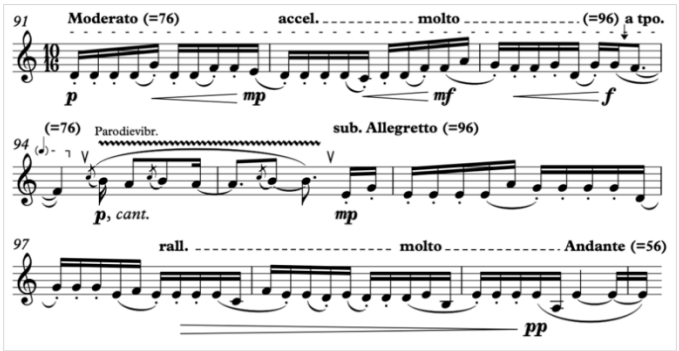

Figure 21: Gareth Flowers Trial 1 Notation

This frame begins with Gareth performing a large passage of music that contains the section above (the longest trial in the study). When the section above is played during this trial, there are incorrect articulations played in measures 91, 92, 93, 96, and 98.

Gareth Flowers Trial 2

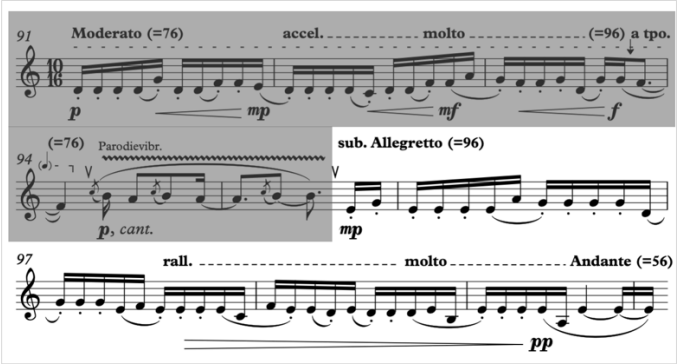

Figure 22: Gareth Flowers Trial 2 Notation

Pick-ups into measure 96 until the end of passage, played ~30 bpm under performance tempo (and a slight printed rallentando), with no identifiable errors present.

Gareth Flowers Trial 3

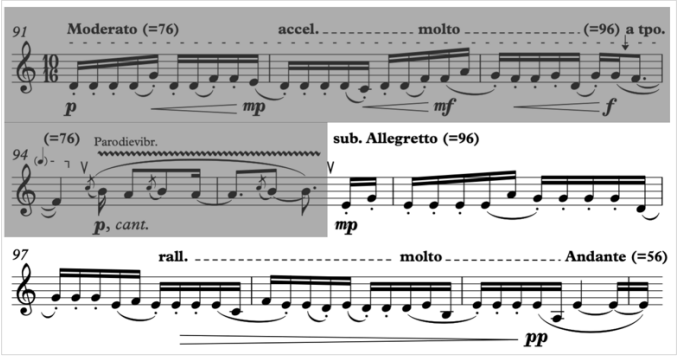

Figure 23: Gareth Flowers Trial 3 Notation

As in Trial 2, the pick-ups into measure 96 until the end of the passage, played ~5 bpm faster than the previous trial. He pulses his left hand on the knee, acting as a metronome. As in Trial 2, there are no identifiable errors.

Gareth Flowers Trial 4

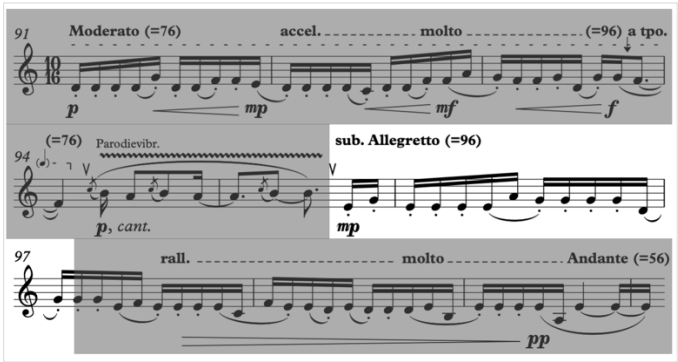

Figure 24: Gareth Flowers Trial 4 Notation

Pick-ups to measure 96 into the downbeat of measure 97, played ~5 bpm faster than the previous trial. The printed D in measure 96 does not have the same resonance as the surrounding notes. Gareth ends the trial immediately.

Gareth Flowers Trial 5

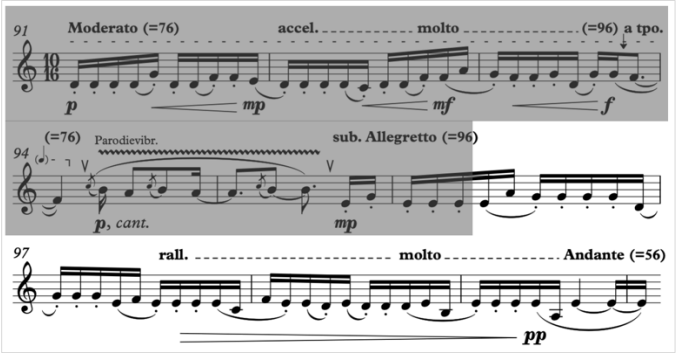

Figure 25: Gareth Flowers Trial 5 Notation

Pick-ups into beat 2 of measure 96 until the end of the passage, played with flexible time, but still more slowly than any trial in this frame (~40 bpm). Although there are resonance errors on the low A in measure 99, the D in measure 96 resonates clearly in time.

Gareth Flowers Trial 6

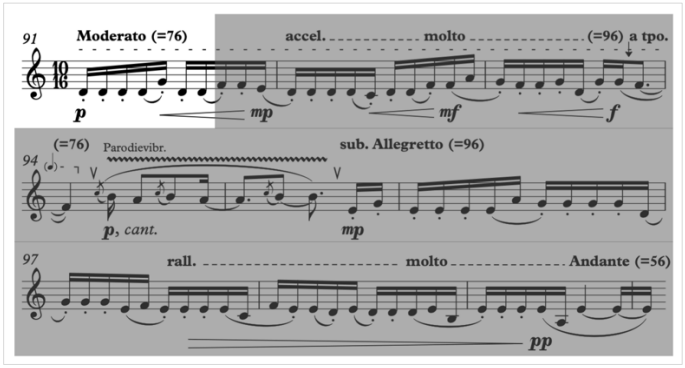

Figure 26: Gareth Flowers Trial 6 Notation

The first 7 sixteenth notes in measure 91, played at about 45 bpm. The target of this short trial is unclear, but there are no identifiable errors.

Gareth Flowers Trial 7

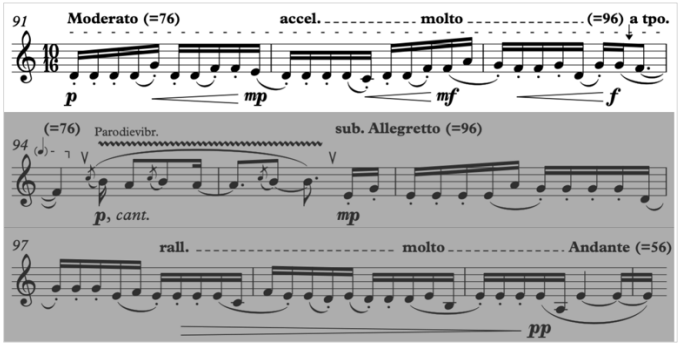

Figure 27: Gareth Flowers Trial 7 Notation

Measures 91-93 played ~10 bpm under performance tempo and slightly out of time. There is one identifiable error as Gareth slurs into the second beat of measure 92 (rather than tongue as printed).

Gareth Flowers Trial 8

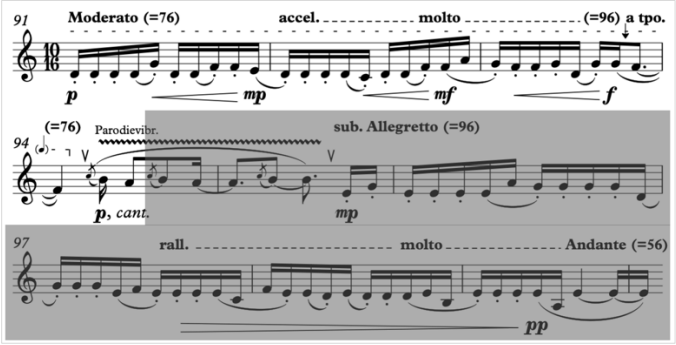

Figure 28: Gareth Flowers Trial 8 Notation

Measure 91 until about halfway through measure 94, played at tempo with inflection and expression. There are no identifiable errors in this trial.

Louis Hanzlik

The following analysis is from Louis' second rehearsal frame where he is practicing the passage shown in Figure 29 from John Wilbye's madrigal, *Sweet Honey-Sucking Bees*. We numbered the measures of this passage as shown in this figure.

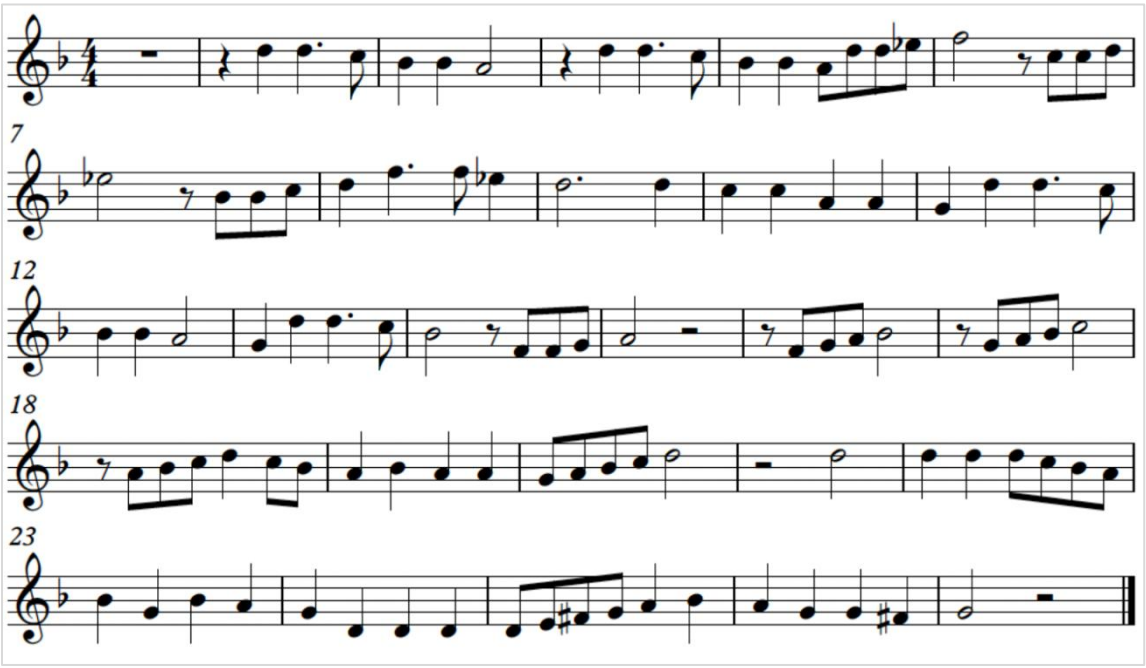

Figure 29: Louis Hanzlik Rehearsal Frame Notation, Wilbye's *Sweet Honey-Sucking Bees*

The rehearsal frame occurs between 6:41-9:01 in the excerpt and contains 11 performance trials ($M = 7.8$ seconds, $SD = 7.68$). Prior to this frame Louis spent practice time on activities directed primarily at discrepancies in measures 1-20. Performance trials make up 1 minute, 26 seconds of the rehearsal frame and non-playing approximations make up 10.6 seconds. The frame contains instances of Louis experimenting with agogic accents in measures 25 and 26 and with period-appropriate ornamentation consisting of rhythmic and melodic diminuition into the harmonic cadence in measure 27. The result is the presence of very few identifiable errors. Instead, the last three measures evolve over the rehearsal frame to more closely reflect what I believe to be Louis's intended expressive intent, and are then recontextualized into larger passages. This frame was chosen as an exemplar of how artist-level musicians doable-ize to refine expressive qualities of passages.

Louis Hanzlik Trial 1

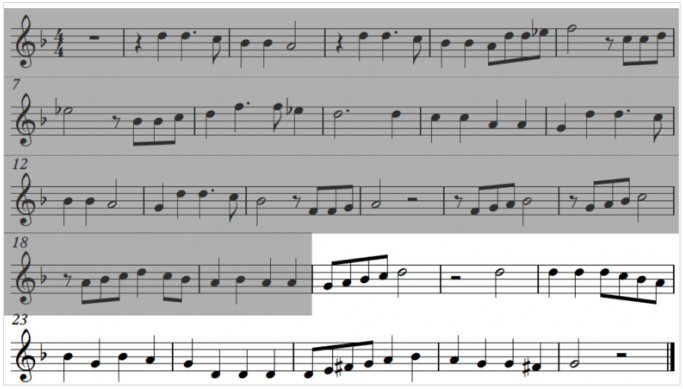

Figure 30: Louis Hanzlik Trial 1 Notation

Measures 20-27, played at tempo with an unmarked ritardando in meaure 26 and ornamentation into the final cadence. There are no identifiable errors in this trial, but each quarter note in measure 26 is performed with approximately the same length. This will change in future trials.

Louis Hanzlik Trial 2

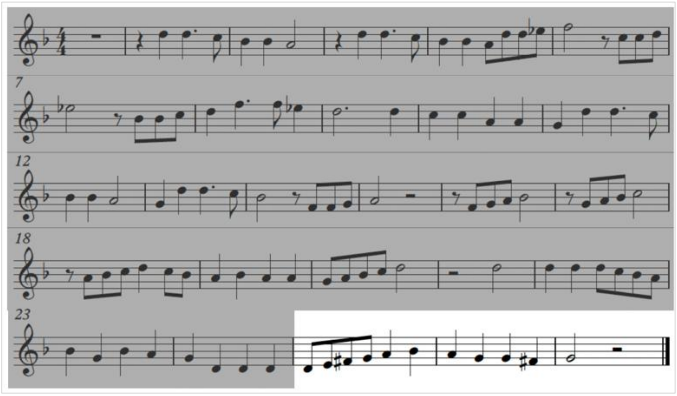

Figure 31: Louis Hanzlik Trial 2 Notation

Measures 25-27, played at tempo, with slight agogic accents on beat 3 of measure 25 and beat 1 of measure 26. Ornamentation added in Trial 1 is present and played in time.

Louis Hanzlik Trial 3

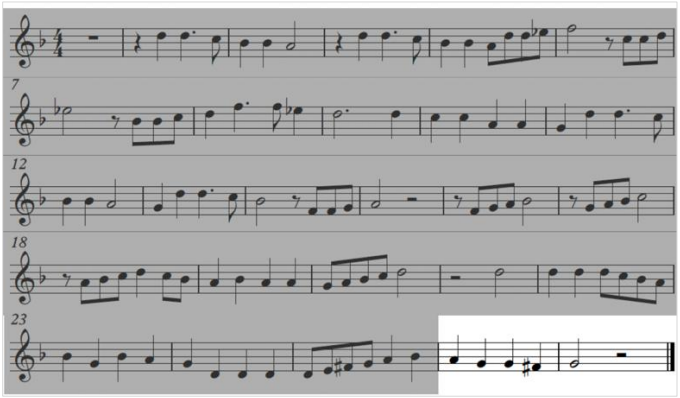

Figure 32: Louis Hanzlik Trial 3 Notation

Measures 26-27, played at tempo with a more pronounced agogic accent on beat 1 of measure 26.

Louis Hanzlik Trial 4

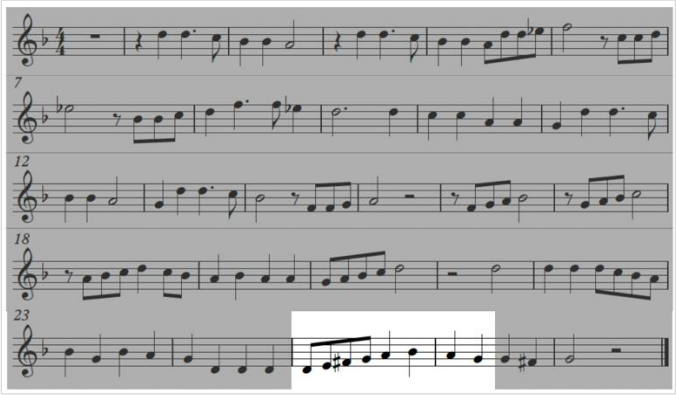

Figure 33: Louis Hanzlik Trial 4 Notation

Measure 25 to beat 3 of measure 26, played at tempo with a heavy agogic accent on beat 3 of measure 25 and lighter agogic accent on beat 1 of measure 26.

Louis Hanzlik Trial 5

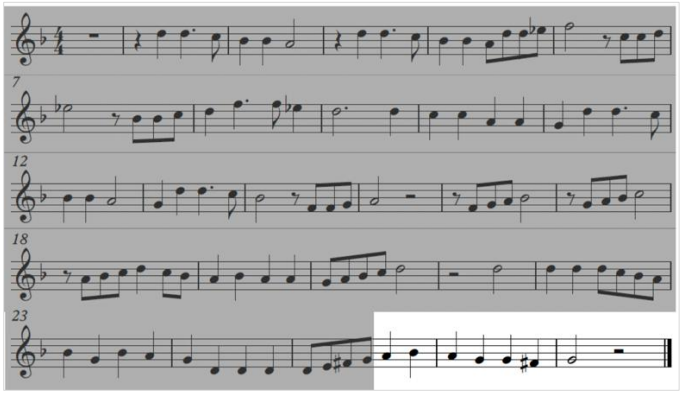

Figure 34: Louis Hanzlik Trial 5 Notation

Beat 3 of measure 25 to the end, played in tempo, with equally pronounced agogic accents on both of the printed A's. Final experimentation with agogic accents. All future trials are consistently performed with the equally weighted accents played in this trial.

Louis Hanzlik Trial 6

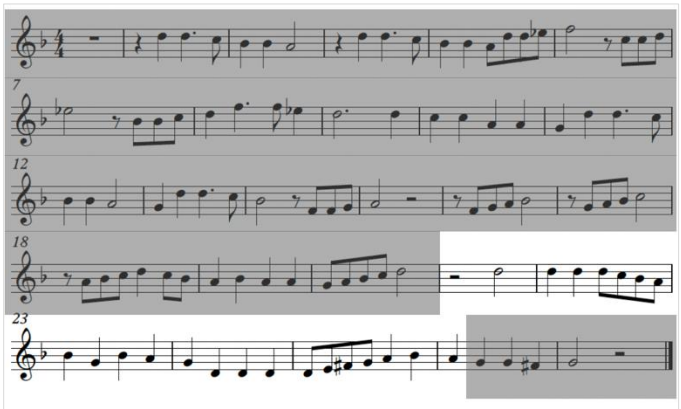

Figure 35: Louis Hanzlik Trial 6 Notation

Measure 21 to beat 3 of measure 26, played in time. One note did not resonate immediately in measure 23, but the agogic accents played in measures 25 and 26 were weighted equally. Much of the trial was also performed slightly behind the metronome.

Louis Hanzlik Trial 7

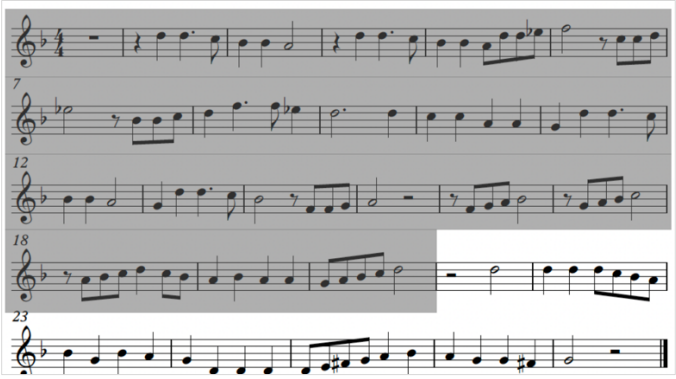

Figure 36: Louis Hanzlik Trial 7 Notation

Measures 21-27, played in time. Agogic accents in measures 25, 26 weighted equally.

Louis Hanzlik Trial 8

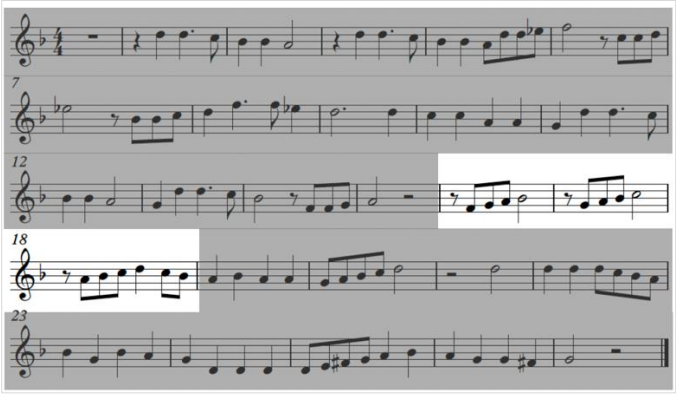

Figure 37: Louis Hanzlik Trial 8 Notation

Measures 16-18, played in time. The printed D in measure 18 is flat. Louis stops trial immediately.

Louis Hanzlik Trial 9

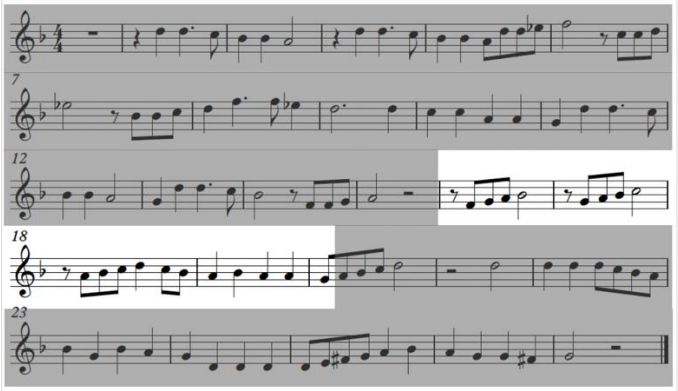

Figure 38: Louis Hanzlik Trial 9 Notation

Measures 16 to the downbeat of measure 20. Played in time with a new ornamentation into the harmonic cadence at measure 20. The printed D in measure 18 is in tune.

Louis Hanzlik Trial 10

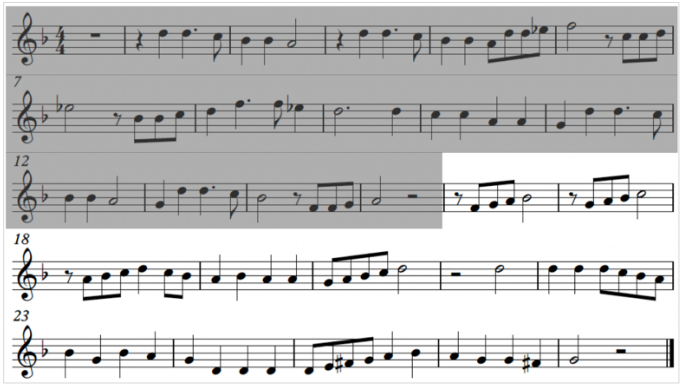

Figure 39: Louis Hanzlik Trial 10 Notation

Measures 16-27, played in time. The ornamentation from Trial 9 is abandoned and agogic accents in measures 25, 26 are again weighted equally.

Louis Hanzlik Trial 11

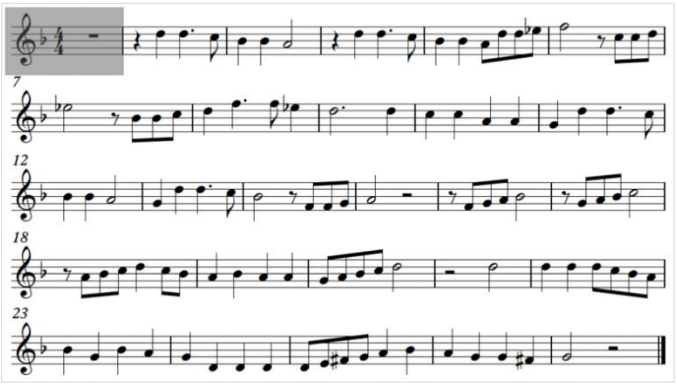

Figure 40: Louis Hanzlik Trial 11 Notation

Measures 2-27, played in time, with inflection. Agogic accents in Measure 25, 26 again weighted equally.

Billy Hunter

The following analysis is from Billy's sixth rehearsal frame during which he practices the passage shown in Figure 41: Measures 17-25 from the fourth movement of Wynton Marsalis' chamber work, *A Fiddler's Tale*.

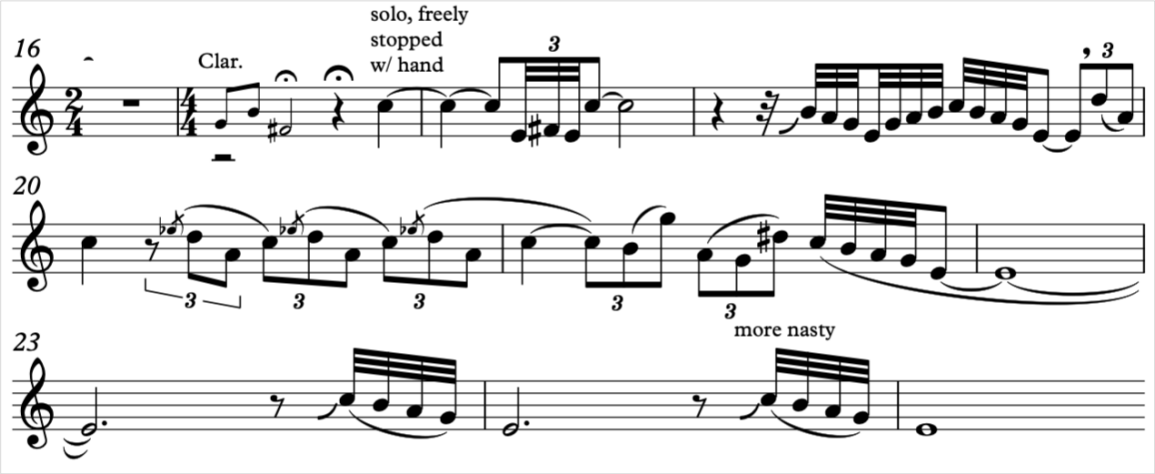

Figure 41: Billy Hunter Rehearsal Frame Notation, Marsalis' *A Fiddler's Tale*

The rehearsal frame occurs between 4:25-7:11 in the excerpt and contains 18 performance trials ($M = 7.1$ seconds, $SD = 10.27$). Prior to this rehearsal frame, Billy had spent time singing and refining, primarily measures 18 and 19. Performance trials make up 2 minutes, 9 seconds of the rehearsal frame and non-playing approximations make up 5.5 seconds. The frame contains instances of Billy experimenting with the plunger mute to perform the passage with his expressive intent. Specifically, he spends focused attention at the melodic interval on the second beat of bar 21 between the written B and G. He adjusts the location of the plunger in relation to the bell of the trumpet, the amount of "closed-ness" of the plunger (the amount of the bell covered by the plunger), and the timing of the motion he uses to transition between closed and open positions (i.e., covered to uncovered). Although plunger technique is typical in jazz reprtoire, it is less common in most classical music. It requires the player to coordinate typical melodic figures with motions in the left hand in ways that are not well-practiced for many orchestral musicians (like Billy).

The grace notes in measure 20 are consistently played incorrectly (as Db's rather than the printed Eb). This persistence suggests that Billy likely does not perceive these as errors during this frame. This phenomenon may be an artifact of the focused attention Billy is aiming at the plunger technique in these measures.

This frame was chosen as an exemplar of how artist-level players explore and experiment with different solutions to produce the sounds they intend to make.

Billy Hunter Trial 1

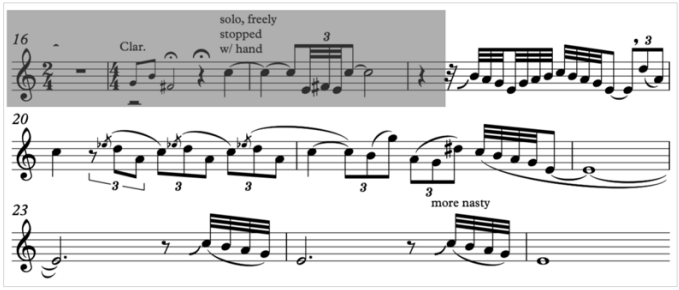

Figure 42: Billy Hunter Trial 1 Notation

Measure 19 to the end of the passage, played with flexible time as marked (i.e.,"freely"), with errors present. Eb grace notes in bar 20 are instead played as Db's, and there is inconsistency in the slur from B-G in measure 21.

Billy Hunter Trial 2

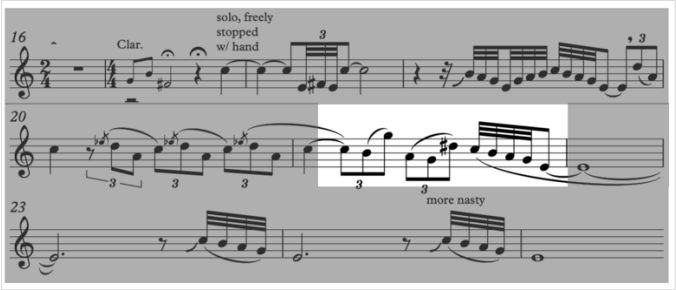

Figure 43: Billy Hunter Trial 2 Notation

Beats 2-4 of measure 21, played in rhythm, but without any plunger mute effects. The first note in the fourth beat doesn't speak precisely in time.

Billy Hunter Trial 3-9

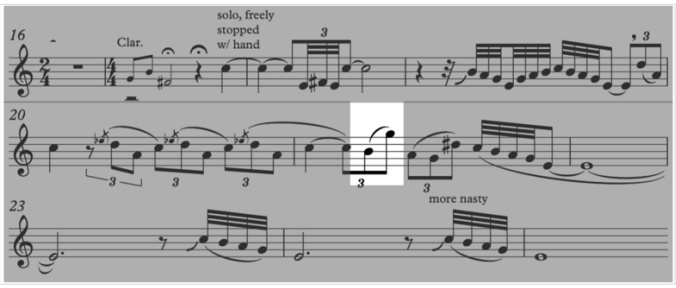

Figure 44: Billy Hunter Trials 3-9 Notation

The interval in measure 21 between B-G, played with adjustments to the timing and pace of oscillating the plunger from open to closed and open again.

Billy Hunter Trial 10

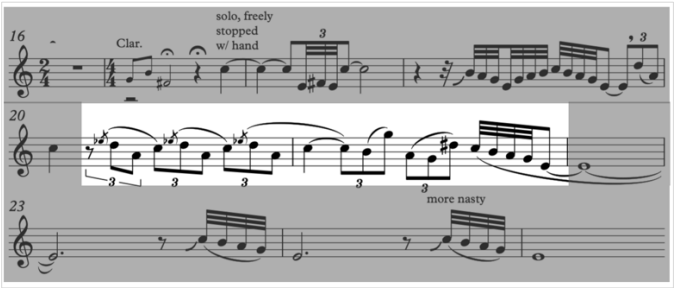

Figure 45: Billy Hunter Trial 10 Notation

Beat 2 of bar 20 to the downbeat of measure 22. There is unevenness in the tone in measure 21 during the leap from B-G.

Billy Hunter Trials 11-13

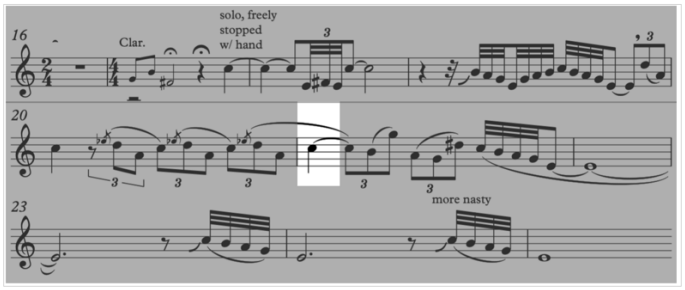

Figure 46: Billy Hunter Trials 11-13 Notation

Simply a concert C (likely the downbeat of measure 21) performed out of time while manipulating tone and pitch with the plunger.

Billy Hunter Trials 14,15

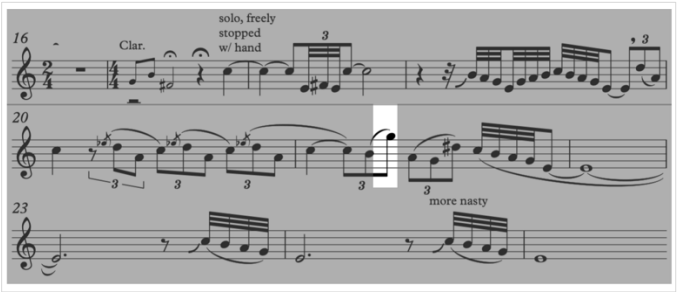

Figure 47: Billy Hunter Trials 14,15 Notation

Simply a concert G (likely the last triplet in beat two of measure 21) performed out of time while manipulating tone and pitch with the plunger.

Billy Hunter Trial 16

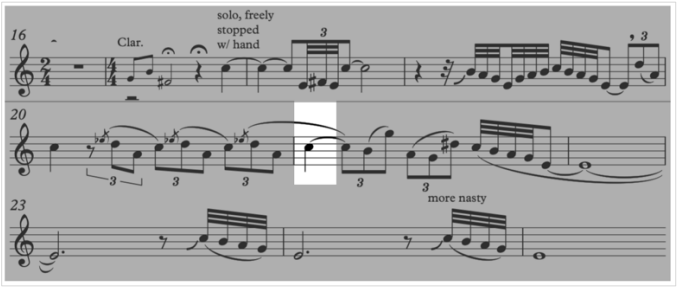

Figure 48: Billy Hunter Trial 16 Notation

Another concert C. While sustaining, Billy errantly jumps up a partial momentarily to an E and stops immediately after the error.

Billy Hunter Trial 17

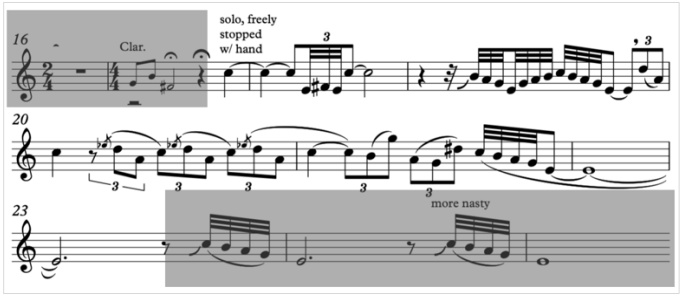

Figure 49: Billy Hunter Trial 17 Notation

From the beginning of the passage in measure 17 until the held long note in measure 23, performed with inflection. The interval in measure 21 addressed in this rehearsal frame is smooth and resonant (although there are other apparent errors).

Billy Hunter Trial 18

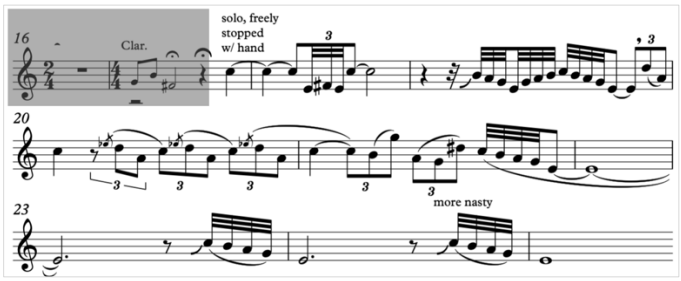

Figure 50: Billy Hunter Trial 18 Notation

The entire selected passage, with inflection. Problematic interval addressed in earlier trials is smooth and resonant.

Amy McCabe

The following analysis is from Amy's first rehearsal frame occurring in which she is practicing the passage in Figure 51 from the third movement of Ida Gotkovsky's *Concerto for Trumpet*.

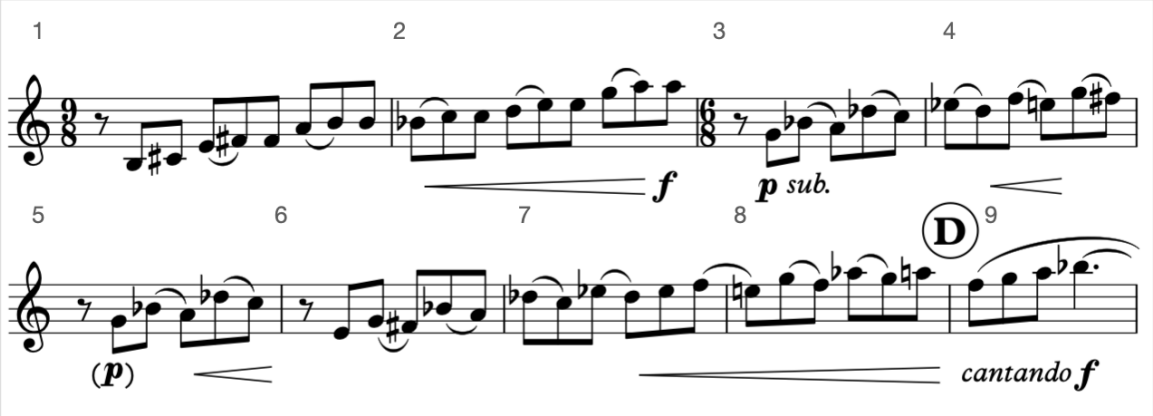

Figure 51: Amy McCabe Rehearsal Frame Notation, Gotkovsky's *Concerto for Trumpet*

Rehearsal Frame 1 occurs between 0:34-2:10 in the recording, and contains 18 performance trials *(M* = 4.2 seconds, *SD* = 2.67). Prior to the start of this rehearsal frame, Amy performed a trial of a larger passage of music that contained the passage in Figure 51, identifying the passage in Figure 51 as a target for improvement.

The total duration of all performance trials in this rehearsal frame is 1 minute 15 seconds. There were no non-playing approximations. In this frame, Amy plays incorrect partials as performance trials approach the target tempo, specifically in the ascending lines in the first four measures of the passage. These incorrect partials are the focus of Amy's attention throughout the frame. We selected this rehearsal frame for detailed analysis because it shows Amy addressing what is perhaps the most stereotypical error that trumpet players make: a missed partial.

In this frame, tempo modifications play a key role in how Amy responds to the relative success of previous performance trials. In general, she speeds up after successful trials and slows the tempo after unsuccessful trials. To reflect this, the analysis below measures tempo from trial to trial in beats per minute (bpm). The peformance tempo marked in the score (dotted quarter = 138) is used as the presumtive target performance tempo.

Amy McCabe Trial 1

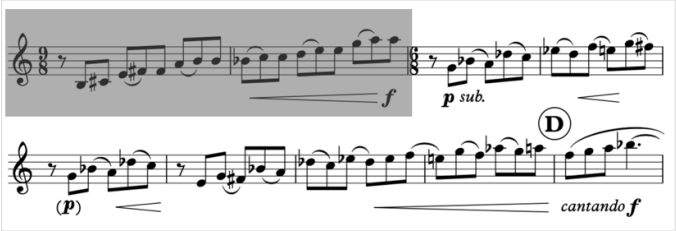

Figure 52: Amy McCabe Trial 1 Notation

Measures 3-9 of the passage are played in-time, around 40 bpm below the performance tempo of 138 bpm (as marked in the full part). Amy plays with a reduced dynamic contrast but with expressive inflection. There are no identifiable errors.

Amy McCabe Trial 2

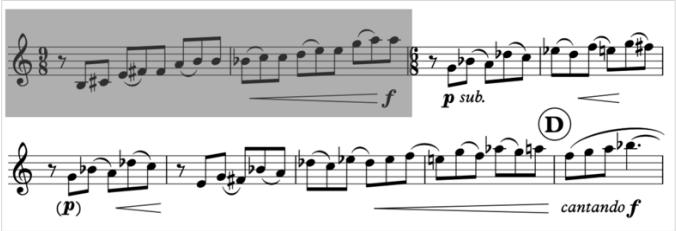

Figure 53: Amy McCabe Trial 2 Notation

Again, measure 3-9 are played in-time, about 20 bpms faster and with more dynamic shape (i.e., moment-to-moment changes in the volume of sound) to the phrase. There are no identifiable errors.

Amy McCabe Trial 3

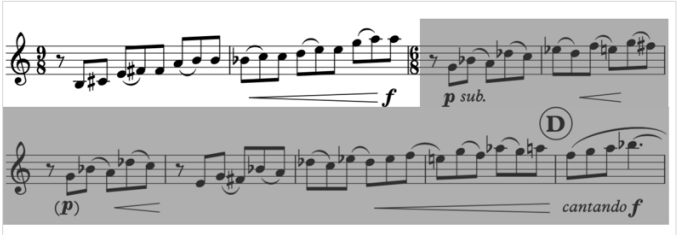

Figure 54: Amy McCabe Trial 3 Notation

The first 2 measures of the passage are played at the same tempo as in Trial 2. In this trial, Amy plays one partial too high on the second beat of the second bar, sounding an F instead of the printed D. Amy stops the trial immediately.

Amy McCabe Trial 4

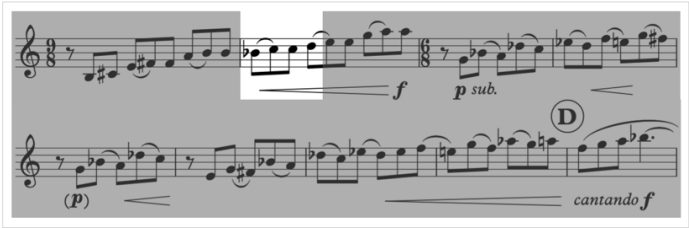

Figure 55: Amy McCabe Trial 4 Notation

Amy plays only the first beat of the second measure (a smaller segment), and plays it more slowly (at about 80 bpm) than she had in the previous trial. The same error from Trial 3 persists.

Amy McCabe Trial 5

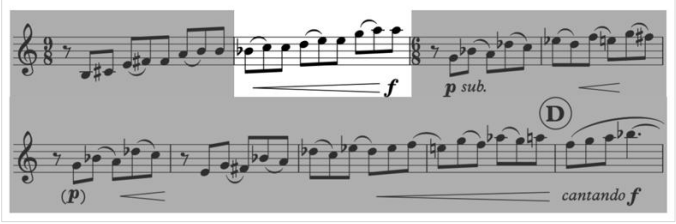

Figure 56: Amy McCabe Trial 5 Notation

Amy plays the entire second measure of the passage, at about 85 bpm. There are no identifiable errors in this trial.

Amy McCabe Trial 6

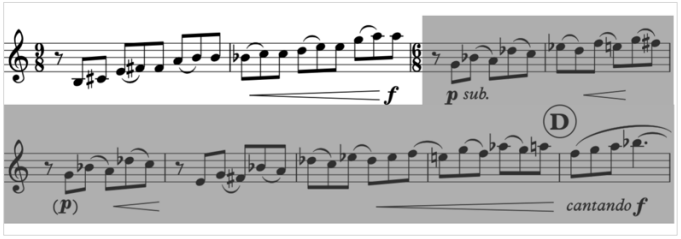

Figure 57: Amy McCabe Trial 6 Notation

Amy combines the first two measures of the passage, playing faster than she had in the previous trial (at about 115 bpm). There are no identiable errors in this trial.

Amy McCabe Trial 7

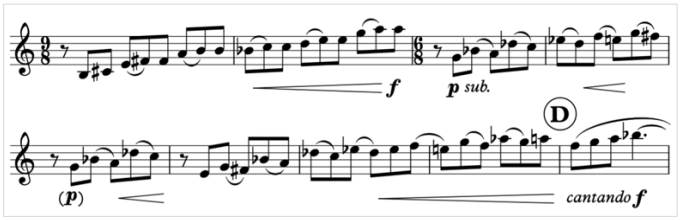

Figure 58: Amy McCabe Trial 7 Notation

The entire selected passage is played at performance tempo and with dynamic contrast. Although the error from trials 3 and 4 did not recur, there is a slight timing inaccuracy (a brief hesitation) going into the final measure.

Amy McCabe Trial 8

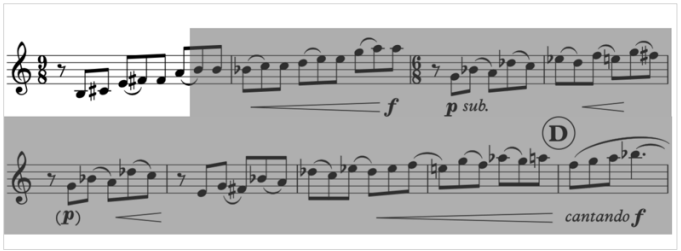

Figure 59: Amy McCabe Trial 8 Notation

Amy plays the first part of the first measure of the passage, missing a partial at the end of the second beat of the first measure, sounding a B rather than the printed F#. Amy stops immediately.

Amy McCabe Trial 9

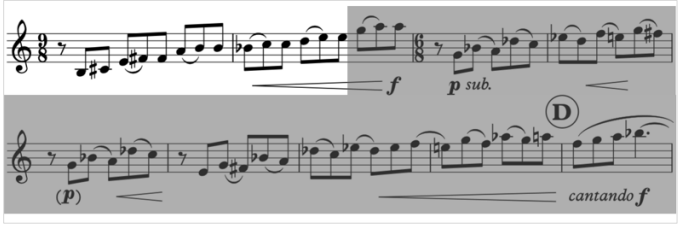

Figure 60: Amy McCabe Trial 9 Notation

Measure 1 until the third beat of measure 2 is played at the slowest tempo of any trial in the rehearsal frame (about 80 bpm). There are no identifiable errors in this trial.

Amy McCabe Trials 10-12

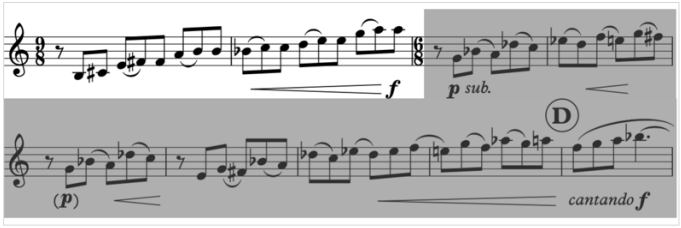

Figure 61: Amy McCabe Trials 10-12 Notation

Amy combines measures 1 and 2 again. She increases both the tempo and the phrase shape in each succeeding trial. There are no identifiable errors.

Amy McCabe Trial 13

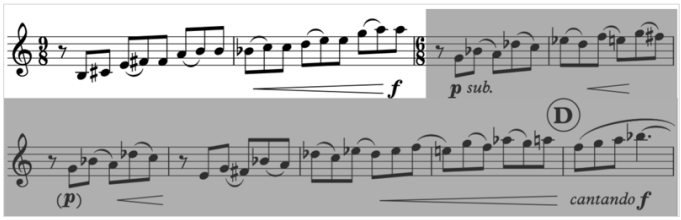

Figure 62: Amy McCabe Trial 13 Notation

Measures 1 and 2 are performed slightly below performance tempo (about 128 bpm) with increased dynamic shape as the melody ascends. There is one identifiable error: in the penultimate note of the first measure, Amy plays one partial too low on the written B, instead sounding an F#.

Amy McCabe Trial 14

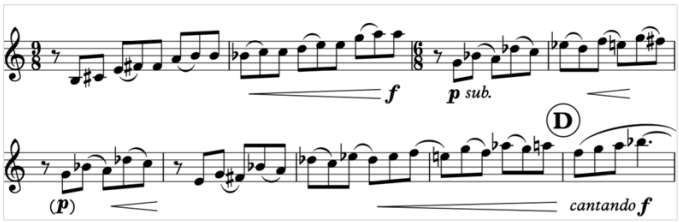

Figure 63: Amy McCabe Trial 14 Notation

The entire selected passage is performed at tempo. There are no missed partials in the opening measures, but some notes in this trial are not as resonant and clear as they had been in the preceding trials.

Amy McCabe Trial 15

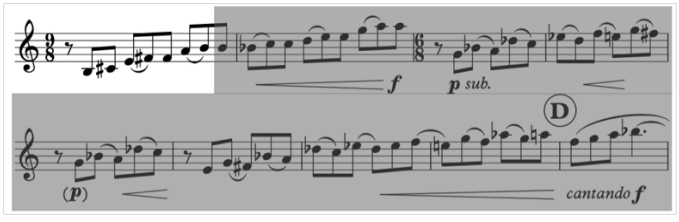

Figure 64: Amy McCabe Trial 15 Notation

Amy plays the entire first measure at tempo, excluding the final note. The written A is not played accurately. Amy stops immediately.

Amy McCabe Trials 16, 17

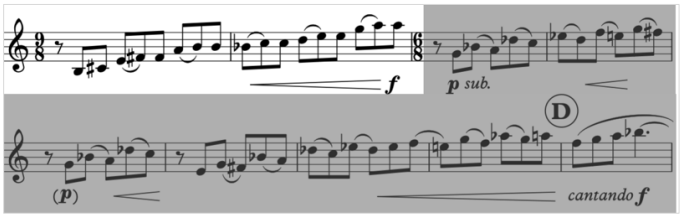

Figure 65: Amy McCabe Trials 16, 17 Notation

Amy again combines measures 1 and 2, playing them below tempo in both trials. Trial 16 is ~25 bpm below tempo; Trial 17 is ~5 bpm below tempo. There are no identifiable errors in these trials.

Amy McCabe Trial 18

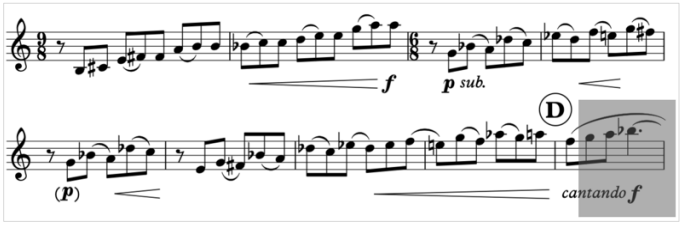

Figure 66: Amy McCabe Trial 18 Notation

Amy plays almost the entire selected passage at tempo. The errors in the first two measures do not occur, but there is another instance of a slight inaccuracy or hesitation in time before the final measure (the same error from trial 7). Amy ends this frame to oil a sticky valve (a mechanical problem on the trumpet), but the following performance trials are directed at a larger passage of music that contains the nine measures in Figure 51, suggesting that the targets of the frame have been reached.