Preparing to Perform: Focus of Attention and Slow Practice in the Preparation for Instrumental Music Performance

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Abstract

Musicians dedicate vast amounts of time to cultivating their skills and preparing for performance. Yet, there is much to be learned about the psychological mechanisms of optimal processes of preparation for musical performance. This dissertation aimed to address these gaps in knowledge. To this end, two aspects of performance preparation were investigated. First, the effects of a psychological approach to performance during the preparatory moments before action execution were examined through two experimental studies of attentional-focus effects on motor-skill performance in violin bowing. Second, the processes of longer-term preparation for performance through music practice were studied through quantitative and qualitative analysis of an online questionnaire exploring reported use of slowness and tempo management in instrumental music practice. Results from analyses of attentional focus effects suggest that violin bow-control skills are improved when performers focus on tactile feedback through the bow compared to focussing on arm movement. This supports previous findings in non-musical contexts that a focus on internal body movement tends to impair motor performance relative to a focus on external action outcomes. Evidence for these effects on physical and physiological aspects of sound production were also shown, and it was further found that expertise may sometimes modulate these effects. Quantitative analysis of slow practice questionnaire data found that slow practice was extremely common among instrumental musicians, and use of slow practice tended to be positively associated with musical self-regulated learning, but not with expertise. Results further suggested that performers may use slow practice to achieve both technical and expressive goals in learning, and that musical performance genre may influence how slow practice is used across the learning trajectory. Furthermore, qualitative findings about slow-practice use presented potential cognitive functions that slow practice may encompass, such as supporting motor learning, regulating the learner's state and supporting deep learning through creative and critical problem solving. These functions are suggested to operate through management of cognitive load, self-regulatory processes, and possibly, facilitation of flow states. Taken together, these findings provide novel insight into processes of musical-skill acquisition and performance preparation that may inform theoretical understandings of music learning, as well as approaches to music performance practice and pedagogy.

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1 Introduction

Somewhere, at this moment, a musician is stepping on to a stage. They could be a classical solo violinist entering a vast concert-hall, a seasoned saxophonist welcoming a familiar audience in a dimly-lit bar, or an aspiring, young rock-guitarist opening the door to their grade-one exam room. In the previous minutes, they may have been absorbed in psychological preparation for the rush of performance. Perhaps practising meditation to focus their mind (Lin et al., 2008), deep breathing to slow their heart rate (Su et al., 2010), or visualising key moments of their performance (Connolly & Williamon, 2004). After greeting their audience, maybe adjusting the music stand and tuning their instrument, there will be a few brief moments in which they may close their eyes, alter their body posture, or take a breath, cultivating a performance state-of-mind. Maybe they are adopting a performing character, such as iconic pop star Beyoncé's famous alter ego Sasha Fierce (Read, 2011). In these brief moments, just before the performance begins, the musician's dedicated preparatory work over the preceding weeks, months, and possibly years, intertwine with in-the-moment preparation of mind and body, to lead to this unique performance.

These processes of music performance preparation, involving the honing of technical skills and the harnessing of psychological strategy, may not always be explicit or formalised in music education approaches. Thus, there is a need to provide evidence-based knowledge on the psychological skills of performance and practice, so that music education institutions can adequately prepare music students for these challenges (Clark & Williamon, 2011). Furthermore, extending understandings of motor-control processes from non-musical tasks to musical contexts can inform theories of skill-acquisition more generally. This dissertation aims to address current gaps in knowledge about psychological aspects of preparation for music performance, addressing two key features of this topic. Firstly, the in-the-moment psychology of performing was investigated through application of an experimental paradigm founded in motor-control studies, which has rarely been applied to musical contexts. This was examined in two studies on the effects of attentional focus on motor-control skills in violin bowing, utilising optical motion-capture, electromyography (EMG), and music information retrieval (MIR) to examine performance outcomes at various stages of action execution. Secondly, longer-term aspects of preparation through practice were studied, through the under-researched topic of slowness in instrumental music practice. This line of research explored new horizons relating to music practice, thus two exploratory questionnaire studies were employed to gain insight into this poorly-understood aspect of music practice from the perspectives of a wide range of musicians. Via these two research threads, the aim was to provide empirically-based evidence on how musicians might use their practice time most efficiently, and utilise a psychological technique to cultivate an optimal performance state-of-mind; the combination of which aimed to present a well-rounded approach to performance preparation. These studies were carried out as part of the research project SloMo: Transformations of Musical Time, which investigated experiences of stretched time and temporality in perception and performance. The current research benefited from the technological facilities afforded by the SloMo project, particularly a motion capture system with integrated wireless EMG sensors, and state-of-the-art sound recording equipment.

This dissertation summary presents an overview of background literature relevant to the current work, a summary of the four studies included, and a discussion of overall findings, implications, and limitations. In Chapter 2, relevant background on preparing for music performance through focus of attention, and through slow music practice is provided. Chapter 3 presents the aims of the dissertation and broad research questions, and Chapter 4 briefly describes the methods of the four studies. In Chapter 5, results from each study are summarised, and in chapter 6 overall findings and implications are discussed. Chapter 7 overviews the limitations of the current work and potential future research directions, and Chapter 8 offers concluding remarks on the current work.

2. Background

2.1 Preparation for Musical Performance

One of the challenges of a musician in preparing and delivering a convincing artistic performance is the need to harness the skills of seemingly polar opposite personas (Kemp, 1996). On the one hand, a musician is required to be quiet and focused in the practice room, diligent in their planning and self-assessment, and unwavering in their commitment to this individual preparation time. On the other hand, a musician must be outgoing and spontaneous when they step onto the stage to deliver the results of their hard work. For musicians who are inclined toward extraversion (Eysenck, 1963), solo practice time might be lonely and unstimulating, while for those who tend more towards an introverted personality (Eysenck, 1963), the stage could be a terrifying place.

Regarding the preparatory work that takes place during music practice, psychological research has aimed, for example, to characterise the ingredients of high-quality practice (e.g., Jorgensen, 2004), the skills required by aspiring musicians to practice well (e.g., McPherson & Renwick, 2011), and the efficacy of specific practice methods (e.g., Donald, 1997; Stambaugh, 2011, 2013). Nonetheless, there remains much to be learned about the processes of preparing for performance through music practice, such as how aspects of tempo and slowness in practice function to support learning. Furthermore, in comparison to research on music practice, performance psychology in music has received less academic attention. Some facets of psychological music performance skills that have been studied include, for example, interventions for the treatment of music performance anxiety (e.g., Cohen & Bodner, 2019; Shaw et al., 2020; Spahn et al., 2016; Stern, 2012), applications of pre-performance routines over the preparatory weeks before a performance (Tief & Gröpel, 2020), and short-term effects of different practising conditions on *choking* under pressure (Wan & Huon, 2005). Fewer studies have addressed psychological approaches in the immediate moments preceding performance. For example, in the anticipatory minutes waiting in the wings before a performance, or the intense moments on stage before the first notes are played. The psychological approach during these breaths before the first musical notes begin to resonate might contain the secrets to unlocking inner potential and achieving musical excellence. Research is needed on both of these aspects of performance preparation, in order to provide a full picture of how music performance skills are acquired, and to equip musicians with these necessary abilities.

2.2 Preparing for Performance through Attentional Focus

One way to explore performance preparation in the moments before action execution is through the performer's focus of attention (FOA). For example, even when a musician has prepared to the best of their ability, the psychological pressure of performing can still affect their ability to play well (Beilock & Carr, 2001). In studies of motor-control, it has been shown that FOA in these key moments of action preparation can influence the likelihood of performance success. This line of research was first pioneered by Wulf et al., (1998) who found that balancing skills were impaired when participants were instructed to focus on their feet compared to when they were instructed to focus on the surface beneath their feet. This observation led to the *constrained action hypothesis* (CAH) (McNevin et al., 2003; Wulf et al., 2001), which stated that an internal focus instruction (on body movement mechanics) would impair motor performance and learning compared to an external focus instruction (on the outcome of the action in the environment). The reasoning behind this effect is that motor processes should function more smoothly and automatically if they are not under the scrutiny of conscious attention (Wulf et al., 2001), and focussing on one's own body movements is thought to evoke self-consciousness and cause attempts to control motor processes which normally operate implicitly (Wulf & Lewthwaite, 2010). At a deeper level, the CAH is founded on principles of the *common coding theory* (Prinz, 1997), which posits that action and perception share cognitive representations and therefore actions are more effective when planned in terms of their sensory outcomes, rather than the mechanics of movement. Research on FOA thus suggests that an optimal state-of-mind in the preparatory moments before a motor skill is performed should avoid conscious attention to the mechanics of body movement.

Support for the CAH has been shown in many different types of motor skill (for a review see Wulf, 2013). However, only a handful of studies have researched FOA effects in music performance skills. While some studies have shown support for the CAH in musical contexts (Atkins, 2017; Duke et al., 2011; Mornell & Wulf, 2019), others have shown mixed or null-effects (Atkins & Duke, 2013; Stambaugh, 2017, 2019). Therefore, FOA may be a useful performance preparation technique for musicians, but the generalisability of the CAH to different types of musical skill is not fully understood. Furthermore, other aspects of FOA that are relevant to music performance skills are its purported impact on the body through physiological and physical aspects of motor-control. For example, it has been found, in non-musical motor-skills, that an internal focus of attention tends to cause less efficient muscle-use (e.g., Neumann, 2019), as well as changes to the organisation of the motor system, measured through physical motion parameters (e.g. Wulf & Dufek, 2009). These features of FOA may have implications for musicians' health, through avoiding excess muscle-tension (Warrington et al., 2002), and optimising efficient and healthy movement habits (Roos, 2001). Nonetheless, these embodied aspects of FOA remain to be explored in the context of music skills.

There are several additional factors that may mediate effects of FOA in music performance, on which little research exists. For example, in non-musical motor-skills, the influence of expertise on FOA effects is debated (Castaneda & Gray, 2007; Perkins-Ceccato et al., 2003; Wulf, 2013), and in sports' research, it has been proposed that beginners may benefit from a focus that is external but close to the body, while experts should perform optimally under a distal focus on the end goal of the action (Singh & Wulf, 2020). In the few music studies on FOA, expertise effects have not been thoroughly investigated (Atkins, 2017; Atkins & Duke, 2013; Duke et al., 2011; Mornell & Wulf, 2019; Stambaugh, 2017, 2019). Similarly, task-complexity may influence how FOA affects performance (Wulf & Prinz, 2001). Two of the studies in which support for the CAH was shown in music performance utilised relatively simple motor skills of key pressing (Duke et al., 2011) and singing (Atkins, 2017). However, many musical instruments necessitate more complex motor-control skills, such as string playing, which requires sophisticated control over bow motion (Schoonderwaldt, 2009), taking years to master basic sound-production (Konczak et al., 2009). It is not known how FOA may affect performance of these complex sound-production skills.

Finally, it has been suggested that performing music may require a different approach to attentional focus than performing non-musical motor-tasks because tactile feedback may play a uniquely important role in producing musical sound (Atkins & Duke, 2013; Stambaugh, 2017, 2019). Indeed, this idea is reflected in principles of somatic training methods, commonly employed in music education to improve performance, which encourage learners to become aware of body sensations while playing (Mattes, 2016). It is currently unknown how preparing for performance of a musical motor-skill by focussing attention on tactile feedback from the musical instrument may affect performance.

In summary, the literature discussed so far suggests that in the moments before an action is carried out, focussing attention on external action outcomes rather than internal movement processes may improve motor skills in music performance. However, there is a lack of research on this psychological performance strategy in musical skills, and especially in complex musical skills. In addition, it has been suggested that focussing on tactile instrumental-feedback may benefit music performance, but this remains to be explored experimentally. Further, understandings of how FOA may impact physiological muscle activity and physical movement outcomes are also not well understood in the context of music performance, and the influence of expertise requires further investigation.

2.3 Preparing for Performance through Slow Practice

So far, preparation for music performance has been considered from the angle of cultivating an optimal performance state-of-mind in the moments immediately before a particular sound-production skill is executed. Taking a different view of performance preparation, we may consider the process of music practice. Individual practice is one of a musician's most important tools when preparing for performance, and understanding what makes quality music practice has been the topic of much research (Jorgensen & Hallam, 2011). However, very little attention has been paid to aspects of tempo and slowness in music practice. As music is an art form that unfolds over time, musicians are equipped with the ability to manipulate and manage tempo during practice, but it is not well understood how practice methods relating to tempo contribute to learning or performance preparation. For example, although slow practice seems an intuitive method for approaching difficult material, biomechanical alterations between slow and fast playing might cause difficulties in learning (Jorgensen & Hallam, 2011). Furthering understandings of the uses and limitations of slow music practice could advance knowledge on how to most optimally utilise tempo and slowness when preparing musical material for performance.

Practising slowly appears to be commonly employed during music practice (Austin & Berg, 2006; Barry & McArthur, 1994; Byo & Cassidy, 2008; Smith, 2005), utilised not only by beginners, but also by expert musicians (Chaffin et al., 2003; Nielsen, 2001). However, the efficacy and cognitive mechanisms of slow practice are poorly understood. Several theoretical concepts related to music learning and performance can be applied to slow practice, and may suggest it as a valuable tool in performance preparation. For example, slow practice may be considered in terms of self-regulated learning; an important concept in understandings of music practice, (Mcpherson et al., 2017), which has been shown to improve music performance (Miksza, 2015). The planning, strategy selection, and self-assessment skills likely involved in using slow practice may imply self-regulation as a key underlying mechanism (McPherson & Renwick, 2011). Similarly, processes involving cognitive load (Owens & Sweller, 2008) may be at play when slow practice is employed. To illustrate, by spreading the amount of information to be processed by the learner over a longer time-period, slow practice may be viewed as reducing *extraneous cognitive load* (i.e., the demands on working memory resources dictated by the instructional technique). In this way, slow practice makes tasks easier. On the other hand, as this process reduces the demands on working memory of simply playing the notes, the learner may be able to redirect working memory resources to focus on the details in the music, in order to build a rich understanding or memorisation of the material. In this way, slow practice may be seen as stimulating *germane cognitive load* (i.e., working memory load caused by schema-building processes). However, further research is needed to test these ideas about cognitive load in slow practice. Finally, slow practice might be considered in terms of experiential and emotional impacts on the learner. For example, making musical material more manageable by reducing tempo may increase enjoyment and motivation for a musician. In fact, this process of matching the difficulty of a task to the skill-level of the performer could be seen as facilitating the state of optimal experience known as *flow*, in which a person becomes fully absorbed and blissfully present in an activity (Csikszentmihalyi, 1990). Experiencing flow during practice may encourage motivation for learning and build performance confidence (Bakker, 2005; Spahn et al., 2021). Therefore, further research on connections between slow music practice, self-regulated learning, cognitive load, and flow would be informative for further understanding how slow practice may contribute to optimal preparation for music performance.

As well as understanding the mechanisms of slow practice, it could also be useful to explore details of the specific techniques of slow practice and their efficacy. For example, key methods which may support the learning of fast music have been identified (along with slow practice) as chunking (a method of inserting pauses into the music by breaking the material into small sections; Prichard, 2017), and rhythm variation (altering the rhythm of a passage so as to add extra time on certain notes; Hallam, 1995). However, it is not known how these practice methods compare with slow practice in how often they are used or how useful they are for performance preparation. Similarly, when using slow practice, tempi may be organised in different ways, such as starting slow and gradually increasing, alternating between one slow and one fast tempo, or switching between different, randomly ordered tempi (Caramiaux et al., 2018; Jorgensen, 2004). Yet, few studies have examined the efficacy of these differing approaches to motor learning. Further investigation of these specific techniques of slow practice and tempo management in music practice can inform understandings of temporal aspects of motor learning, as well as more detailed knowledge of music preparation, specifically.

Overall, current understandings of how and why slow practice and tempo manipulation may be used to support music learning are sparse. As slow practice appears to be a common and intuitive method used by musicians, building understandings of the mechanisms and techniques of slow practice appears to be a useful avenue for developing knowledge about optimal performance preparation through music practice.

3 Aims

The aim of this dissertation was to investigate the psychological and psychomotor mechanisms of optimal preparation for instrumental music performance. Based on previous literature, two aspects of performance preparation on which knowledge was lacking were identified; effects of attentional focus on instrumental music performance skills, and psychological mechanisms of slowness in instrumental music practice. Addressing performance preparation from these two differing angles was intended to provide a well-rounded understanding of the factors contributing to music performance preparation. The broad research questions were:

RQ1. How might attentional focus instructions, applied in the preparatory moments before action execution, affect physiological, physical, and acoustic aspects of motor performance in violin bowing?

RQ2. Will effects of attentional focus instructions depend on violin-playing expertise?

RQ3. Through what cognitive and psychomotor mechanisms might slow practice support instrumental music learning?

RQ4. How do instrumental musicians perceive slow practice to be useful or not useful in learning?

To address these questions, four studies were carried out. The first two studies constituted lab-based behavioural experiments investigating effects of verbally administered attentional focus instructions, given immediately before a task was performed, on motor-skill performance in violin playing (data collection one, RQ1 and RQ2). This topic addressed a psychological aspect of performance preparation in the moments immediately preceding action execution. As the topic of FOA is well-established in non-musical motor-control research, these studies were primarily hypothesis-driven, with the aim of replicating previous findings about the influence of FOA on motor skills, as well as expanding understandings of FOA to the specific context of violin-bowing skills. Furthermore, in order to deepen understandings of this topic, FOA effects were examined on physical movement outcomes and physiological muscle activity, as well as acoustic measures of sound-production. The second two studies aimed to explore preparation for performance in a different sense; as (slow) music practice which may take place over a long period of time, incorporating cognitive and motoric aspects of learning, as well as both expressive-interpretative and technical goals. These studies comprised broad investigations into the use of slow practice among instrumental musicians from varying musical backgrounds, through an online questionnaire (data collection two, RQ3 and RQ4). As very little previous research exists on the topic of slow music practice, the second two studies consisted of exploratory analyses (one quantitative and one qualitative). Taken together, these four studies contribute to understandings of psychological aspects of preparation for musical performance, considering two key aspects of performance preparation, which may come together to support optimal music performance.

4 Study Summaries

4.1 Data Collection One (Studies One and Two)

This data collection aimed to test effects of FOA instructions, in the preparatory moments before action execution, on motor skill performance in two violin-bowing tasks. Participants were experienced upper-strings musicians ($N = 16$), and non-string playing musicians ($N = 16$). One bowing task involved basic open-string tone-production skills, with outcome measures of acoustic features of violin sound, motion parameters of the violin and bow, and EMG of muscle activity in the bowing arm. These measurements provided data for Study 1, investigating effects of preparatory FOA on execution of tone-production skills. The second task involved a slow-motion bow-control exercise in which participants aimed to produce single oscillations of the string at a time, taken from a well-known book of violin exercises (Fischer, 1997). Outcome measures were number of click sounds (i.e., oscillations), and number of errors (i.e., bow-slips) produced, and EMG of bowing-arm muscle activity. Additionally, participants' reported thoughts during task performance were analysed. This second task provided data for Study 2, investigating effects of preparatory FOA on execution of bow-control skills. For both bowing tasks, three focus instructions were given. The instructions were: 1) Internal: focus on arm movement, 2) External: focus on sound produced, and 3) Somatic: focus on the resistance of the bow against the string. While both the external and somatic instructions constitute types of external focus, as they do not refer to body movement (Wulf, 2013), the somatic focus intended to additionally bring attention to tactile instrumental feedback. All participants carried out both tasks under the three attentional focus instructions, in a repeated-measures design.

4.1.1 Equipment and Experimental Set-up

The bowing tasks were performed by all participants on the same violin, mounted with a contact microphone, and reflective motion capture markers. Participants were outfitted with wireless surface EMG sensors on the bicep, triceps, and deltoid muscles of the right arm. Motion capture and EMG data were recorded through Qualisys Track Manager (QTM) software, allowing synchronisation of the two data streams, while the audio recording was synchronised with QTM via SMPTE time code.

4.1.2 Procedure

Participants underwent a short training session and practice time in which they learned how to carry out the bowing tasks. Next, participants were informed that they would receive three different focus instructions describing what they should think about when performing. The experimenter then read aloud the first focus instruction and participants performed three trials of each task under this focus. Participants were then asked to verbally report what they were thinking about during the tasks, and their answer was transcribed by the experimenter. Next, there was a one-minute rest period, in which participants sat quietly before moving on to the next focus instruction (the order of focus instructions was counterbalanced across participants).

4.1.3 Measures

Audio. For task 1, acoustic timbral features of spectral centroid, roughness and root mean square (RMS) were extracted, using the Music Information Retrieval Toolbox (Lartillot & Toiviainen, 2007). For task 2, the data was manually scored for number of clicks (individual string oscillations), and errors (sound events showing multiple oscillations).

Motion Capture. Data were processed in QTM software and MATLAB using the Motion Capture Toolbox (Burger & Toiviainen, 2013). Outcome measures were bow contact point (the distance of the bow on the string, relative to the bridge, *M* and *SD*), scroll sway (*SD* of the scroll marker in the medio-lateral axis), and bow acceleration (mm/s^2, *M* and *SD*).

Electromyography. Data processing was carried out in custom MATLAB software. A mean RMS value for each muscle was calculated in order to give an indication of the power of muscle activity.

Reported thoughts. An exploratory text-based analysis was carried out to identify themes in the data related to theoretical conceptions of FOA effects. The descriptive frequency of these themes across focus conditions was inspected.

4.2 Data Collection 2 (Studies 3 and 4)

This data collection aimed to investigate instrumental musicians' reported use and perceptions of slow music practice in learning and preparing musical material, through an online questionnaire. As very little previous research exists on techniques and functions of slow practice, the aim was to sample a diverse range of musicians (182 classical musicians, 74 non-classical) in order to inform initial, broad understandings of how and why slow practice may be used, and to consider the influence of individual differences. The questionnaire consisted of 7-point rating items about practice behaviours, as well as open-ended qualitative questions about slow practice, and the musical self-regulated learning questionnaire (Ritchie & Williamon, 2013). Further questions about mental practice and experiences of flow during practice were included in the questionnaire, but not analysed in the current studies. In Study 1, quantitative aspects of reported slow-practice use were analysed pertaining to the reported prevalence of certain slow practice strategies, and possible relationships between use of slow practice with self-regulated learning and musical expertise. Building on the findings of Study 1, Study 2 presents a qualitative analysis of open-ended responses about perceived uses, limitations, and specific techniques of slow practice.

5 Results

5.1 Study 1 Results

Effects of attentional focus instructions were analysed with repeated measures Analysis of variance (ANOVA) for each outcome variable. Results revealed significant effects of focus condition on spectral centroid of violin tone (acoustical stage of sound production), consistency of bow contact-point (physical stage), and deltoid muscle activity (physiological stage), regardless of expertise. Further, there was a significant effect of focus condition on violin scroll sway for novices, but not for experienced players, and there were no effects of focus condition on RMS or roughness of violin tone, bow acceleration, or bicep muscle activity. Additionally, there were no significant correlations between outcome measures.

Post-hoc analyses showed several significant differences between the somatic focus on bow-string resistance, and the other two focus conditions. Spectral centroid was found to increase under somatic focus relative to internal focus, which can be interpreted as an improvement to brightness of tone under the somatic focus condition (Lukasik, 2005; Trapasso, 2013). Further, bow contact point, was more consistent (lower *SD*), indicating improved bow control, in the somatic condition relative to the external condition. For EMG measures, deltoid muscle activity was significantly decreased under somatic focus relative to internal focus, which may indicate more efficient muscle use under somatic focus. Finally, novices' violin sway was significantly increased under somatic focus relative to internal focus, also considered a performance improvement by increasing freedom of body motion (Roos, 2001).

Several main effects of expertise on performance outcome measures were also found. Compared to novices, experienced violinists played with a quieter, less rough sound, with higher consistency in RMS, spectral centroid, and roughness. They played with higher variability of bow acceleration, with a contact point further from the bridge, and with a greater amount of violin sway. FOA effects mostly occurred regardless of expertise, although an interaction effect of expertise and focus condition was observed for the measure of violin sway, with this effect evidenced in novices only.

5.2 Study 2 Results

As in Study 1, effects of focus condition on outcome measures were analysed with repeated-measures ANOVAs. There was a significant interaction effect of focus condition with expertise on the outcome number of errors, such that experienced players made fewer errors under somatic focus relative to internal focus, while novice players' errors were not significantly affected by focus instruction. There were no significant differences between the internal focus and the external focus on sound, and no significant effects or interactions on number of clicks.

For EMG measures, there was a main effect of focus condition on triceps activity such that muscle activity was reduced under somatic focus relative to internal. This is in line with findings from Study 1 that an external focus may promote more efficient muscle activity than an internal focus. Results also showed that experienced players had significantly higher bicep muscle activity than novices, while there were no effects of FOA on deltoid muscle activity.

Finally, through analysing participants' reported thoughts during task performance, an overview of how FOA may influence conscious thinking was provided. Descriptively, participants exhibited thoughts related to letting go of control during performance more often in the external and somatic focus conditions relative to the internal focus. Additionally, some participants exhibited intuitive understanding of constrained action effects, noticing that their performance improved under the external conditions.

5.3 Study 3 Results

Reported use of slow practice was extremely common in both classical and non-classical musicians. ANOVA results showed that, compared with techniques of chunking and rhythm variation, slow practice was rated as significantly more frequently used, across both classical and non-classical groups. Regarding methods of slow practice, gradually increasing tempo was reported as significantly more frequently used compared to alternating tempi and random tempi selection, also across both music-genre groups. Further, both expressive and technical goals of slow practice were reported as frequently used (i.e., rated higher than the mid-point of the scale), with technical goals significantly more frequently reported than expressive, across both music-genre groups.

Principle Components Analysis (PCA) on raw ratings items revealed three different components relating to slow practice. These components were named Expressive slow practice (high scores indicating more use of slow practice for expressive goals), Technical slow practice (high scores indicating more use of slow practice for technical goals), and Preparatory slow practice (high scores indicating more use of slow practice to prepare for further practice or performance). Multiple regression analyses, showed that all three slow practice components were positively associated with Musical Self-Regulated Learning (MSRL), when music-performance genre was disregarded. No main associations of any slow practice components with musical expertise (years of training) were found. However, for preparatory slow practice, there was an interaction effect of music-performance genre with MSRL and expertise. In classical musicians, use of preparatory slow practice was positively associated with both MSRL and expertise, indicating that more experienced classical musicians, with higher self-regulated learning tended to use more preparatory slow practice. Conversely, in non-classical musicians there was a negative association between preparatory slow practice and musical expertise, and no association with MSRL.

5.4 Study 4 Results

Qualitative analysis was carried out on open-ended responses to questions about reasons for using slow practice, goals of slow practice, techniques of slow practice, and limitations of slow practice. The data was analysed using thematic analysis according Braun and Clarke's (2006), six-step process, and coding was driven by the content of the data (inductive coding). Analysis was carried out in MAXQDA software. Nine themes were identified, which were then organised into three higher-level themes: Perceived functions of slow practice, Perceived pitfalls of slow practice, and Specific practice techniques. Within Perceived functions of slow practice, there were four themes, each describing a function of slow practice: Managing information load; Regulating states (categorised into emotional, mental, and perceptual states); Building a foundation for motor learning; and Creative and critical problem solving. Within Perceived pitfalls of slow practice, there were two themes: Strategic pitfalls (strategies of using slow practice perceived to be suboptimal or harmful to learning), and Malfunctions of slow practice (specific ways in which slow practice could harm learning, divided into emotional-cognitive malfunctions and technical-practical malfunctions). Finally, within Specific practice techniques, there were three themes: Tempo organisation (how different tempi may be organised within slow practice), Complimenting techniques (non-slow techniques used alongside slow practice), and Avoiding slow practice (reports of deliberately limiting or not using slow practice).

6 Discussion

Below, theoretical and practical implications of the current findings are discussed with a view to informing present understandings of the psychology of music performance preparation. Discussion points pertaining to effects of attentional focus in preparation for motor-skill execution are drawn from results of Studies 1 and 2, while discussion of slow music practice as a method of preparing for performance draws on results from Studies 3 and 4.

6.1 Focus of Attention

Addressing RQ1, the effect of attentional focus instructions, applied in the preparatory moments before action execution, on performance of violin-bowing skills was investigated. Overall results indicated that focusing externally on bow-string resistance improved motor-control ability compared to focusing internally on arm movement. On the other hand, focussing on sound did not show performance improvements relative to the other two foci. Results further showed effects of FOA on physiological muscle activity, and on aspects of instrument motion, as well as providing insight into how FOA effects may sometimes be mediated by expertise. Overall, results indicate that a psychological approach, in the form of attentional focus, applied in the preparatory moments before action execution may be of importance to performance success. Findings are discussed in more detail below.

6.1.1 Effects of Preparatory FOA on Performance Ability

The current findings highlight the importance of in-the-moment psychological performance preparation, and the influence that a few words from a coach or a teacher may have on the performer. In line with previous understandings of attentional focus (Wulf et al., 2001), it was shown that, in the context of violin-bowing skills, an external *somatic* focus on bow-string resistance improved motor performance relative to an internal focus on arm movement. This was shown via improvements to tone brightness in a tone-production task for both experienced and novice players, and through a reduction in errors during a bow-control exercise for experienced players only. This beneficial effect of focusing on tactile instrumental feedback supports assertions that tactile information is important to musical performance (Stambaugh, 2017, 2019). Furthermore, this result is consistent with previous findings showing the benefits of an external focus (i.e., not focussing on body movement) in performance of other music tasks (Atkins, 2017; Duke et al., 2011; Mornell & Wulf, 2019), and is in line with principles of somatic training methods, which encourage awareness of body sensations in performance preparation (Mattes, 2016). These results can inform approaches to teaching or coaching instrumental musicians, suggesting that directing a performer's attention towards the body mechanics of the action they wish to perform may produce suboptimal performance. Moreover, in several cases, the observed FOA effects applied, not only to novices, but also to experienced players when performing a very basic sound-production skill, further highlighting the potential impact of psychological preparation skills even on well-learned motor tasks.

Conversely, no performance benefits were found of an external focus on sound. This is not in line with the CAH (Wulf et al., 2001), or previous findings that focussing on sound was beneficial to musical motor tasks (Atkins, 2017; Duke et al., 2011). A potential explanation for why focussing on sound did not benefit performance in the current studies is that the complexity of violin-bowing skills (Edgerton et al., 2014; Konczak et al., 2009) may necessitate that performers maintain some element of conscious attention to instrument technique. In other words, because of the complex relationship between action (bowing movements) and outcome (sound production), focussing on the end goal of the action (the sound) was not enough to support motor skills. Rather, the performers required an external focus more closely situated to instrument technique. This would be in line with similar findings in volleyball, that a proximal-external focus best supports performance when movements are not fully automated (Singh & Wulf, 2020). This finding provides a novel perspective on optimal FOA in a complex sound-production task.

Overall, these findings show that attentional focus instructions as an in-the-moment performance-preparation technique may impact motor-control ability in violin-playing skills. For the bowing tasks assessed, focussing on tactile instrumental-feedback appeared to be a beneficial performance strategy, while focusing on movement of the bowing arm, or on sound, appeared to be less helpful.

6.1.2 Underlying Mechanisms of FOA Effects

The theoretical implications of the current findings on FOA in violin performance are not completely clear, and require further investigation. On the one hand, the evidence in support of the CAH, suggests that there are similarities between musical motor-skills and non-musical motor-skills in action-control processes. Broadly speaking, the current findings support ideas of cognition as embodied, with shared representation of perception and action, as defined in common-coding theory (Prinz, 1997). This is because the CAH is based on the understanding that actions are planned in terms of their sensory outcomes, thus an external focus best supports action planning (Wulf, 2013). However, as current results did not fully support the CAH (an external focus on sound did not improve performance), this may suggest differing cognitive mechanisms for musical motor-skills. As discussed above, this may be due to the complex motor parameters involved in instrumental sound-production. In addition, there may be other factors that influenced FOA effects in the current research. For example, individual differences such as personality, training in somatic methods, or tendency towards conscious control (Masters & Maxwell, 2008) may have interacted with FOA effects. Indeed, exploratory analysis of performers' conscious thoughts showed that a few performers were aware of constrained action effects, highlighting individual variation in this aspect. Therefore, further research is needed to understand the full complexity of this phenomenon, and different factors that may influence it.

Present findings regarding effects of FOA on performers' physiology and physical movement behaviour may further shed light on the underlying mechanisms of this psychological performance approach. Current results were generally consistent with previous literature suggesting that an internal FOA produces less efficient muscle-use than an external FOA (Marchant & Greig, 2017; Neumann & Brown, 2013; Vance et al., 2004). Thus, increased efficiency of muscle use may be one mechanism through which an external preparatory FOA might improve performance outcomes. Furthermore, it was found that preparatory FOA affected physical aspects of performers' action, in terms of violin sway and consistency of bow positioning. These findings indicate that focussing on tactile instrumental feedback may improve performance via physical changes to motor control, in line with previous studies of FOA effects in sport (e.g. Wulf & Dufek, 2009). These results may further have implications for musicians' health, as reducing excess tension and postural stiffness through attentional focus may help performers to avoid injuries (Mattes, 2016; Vergara & Page, 2002; Warrington et al., 2002). Further research could explore associations between attentional focus and experiences of pain or injury in musicians.

Another previously suggested mechanism of FOA is that an internal focus causes increased self-consciousness during performance preparation (Wulf & Lewthwaite, 2010). In the current studies it is not clear if this happened. Our descriptive analysis of performers' conscious thoughts during performance indicated that while focusing externally, participants had more thoughts related to letting go of control, suggesting that efforts to deliberately control action may have happened less in the external foci. However, there was no evidence of changes to self-conscious thoughts. Further research could combine investigation of conscious thinking-patterns with neural measures (Law & Wong, 2020) to better understand if an increase in self-consciousness might trigger the observed changes to the body and to performance.

Finally, in order to understand the mechanisms behind effects of attentional focus on performance skills, it would be useful to show how physical, physiological, and auditory aspects of performance were related. In the current research no significant associations between performance measures were identified. Therefore, it is not possible to know, from the current data, if changes to muscle-use efficiency or motor-system organisation were responsible for changes to sound-production. It is likely that other unmeasured factors were involved, such as bow force, specific bow technique or additional postural features. Therefore, further research could aim to measure, or control, more aspects of sound-production technique in order to gain a clearer picture of how FOA effects work to influence sound-production.

Overall, the current findings do not offer a definitive answer as to the underlying mechanisms of FOA effects. However, results suggest that processes of constrained action, manifest in physiological and physical alterations to motor control, take place as a result of attentional focus instructions. Further research should aim to explore the role of self-consciousness in these processes.

6.1.3 Expertise Effects

As previous research on FOA in music contexts has provided little consensus on the influence of expertise on FOA effects, the current research aimed to address this issue. Results suggested that for most measures, effects consistent with the CAH occurred regardless of expertise. However, in some cases there were interaction effects between expertise and FOA. Overall, these findings suggest that both novice and experienced players can be susceptible to constrained action effects, in line with assertions from Wulf (2013), but that in some cases expertise may also mediate FOA effects, as some previous studies have found

(Castaneda & Gray, 2007; Perkins-Ceccato et al., 2003). On the one hand, this points to the versatility of attentional focus as a preparatory performance-technique, in that it may be useful to both beginners and experts. On the other hand, these results also show how attentional focus effects can be task specific, or mediated by individual differences.

Another factor that may have impacted FOA effects in the current work is task familiarity, as it has been suggested that FOA might not affect performance outcomes if performers find the task too easy (Wulf & Prinz, 2001). The open-string bowing task was very familiar and easy for experienced players, but unfamiliar and possibly difficult for novices. Conversely, the slow-motion bow-control task was equally unfamiliar for both novices and experienced players. Therefore, differences in task familiarity between groups may account for some of the expertise effects in the current findings. Thus, further research is needed to clarify the role that expertise may play in defining optimal FOA in music performance preparation.

6.1.4 Focus of Attention Conclusions

Overall, the current findings provide evidence that adopting an attentional focus on bow-string resistance in the moments immediately preceding performance can improve motor-control ability in violin-bowing skills. This highlights the importance to music performance skills of psychological preparation. Regarding the underlying processes of these attentional focus effects, results partially support mechanisms of constrained action caused by focussing on internal body movement mechanics, leading to impaired performance, as well as physical and physiological changes to the motor system (Neumann, 2019; Wulf et al., 2001; Wulf & Dufek, 2009). This implies similar motor-control mechanisms in music-based motor-tasks as non-musical tasks. However, in contrast to previous findings (Atkins, 2017; Duke et al., 2011), there were no observed benefits of focussing on sound, suggesting that focussing on tactile feedback may be a specifically beneficial approach for complex instrumental sound-production skills (Stambaugh, 2017). Findings also indicated that directing attention towards tactile instrumental feedback was capable of improving performance for both novices and experienced players, highlighting that even when skills are well-learned, a preparatory psychological technique may still have an effect on performance. Therefore, for musicians who have worked hard in the practice room, but struggle with performance pressure, FOA may be a useful tool for boosting performance success. On the other hand, for some outcome measures, expertise did influence FOA effects, and further research is needed into how individual differences, task familiarity, and task difficulty may mediate effects of attentional focus.

6.2 Slow Practice

Addressing RQ3 and RQ4, preparation for music performance was examined from a different angle, considering the underlying processes of instrumental music practice. In particular, slow practice was investigated; a prevalent, but under-researched method of preparation for performance. Results showed that slow practice was a very common strategy, with multiple possible functions in learning, largely perceived by instrumental musicians as a useful or essential practice method. Findings suggested that self-regulatory processes, management of cognitive load, and cultivation of flow states may constitute some of the underlying mechanisms of slow practice. Further insight into specific techniques of tempo management were also provided. These findings may inform understandings of musical-skill acquisition, and optimal methods of performance preparation through practice.

6.2.1 The Importance of Slow Practice in Performance Preparation

Several of the current findings support the notion that slow practice is important to music learning and performance preparation. For example, using slow practice was found to be extremely prevalent among both classical and non-classical musicians, consistent with previous literature (Austin & Berg, 2006; Barry & McArthur, 1994; Byo & Cassidy, 2008; Smith, 2005). Furthermore, ratings of how often slow practice was used were high across different expertise levels, suggesting that slow practice may be commonly-used by experts and beginners alike. Adding to this picture of slow practice as ubiquitous and often-used, it was found that perspectives on slow practice were largely positive, with most participants viewing slow practice as a useful and even necessary part of preparing new musical material. Although respondents also indicated that there were downsides to slow practice, questionnaire responses, in general, contained more information on positive aspects of slow practice. Further, it was found that those who reported higher use of self-regulated learning strategies (Ritchie & Williamon, 2013) also reported more use of slow practice (in both classical and non-classical musicians). This may imply that slow practice involves some aspect of self-regulation, which is widely agreed to indicate good quality practice (Miksza, 2015; Nielsen, 2001). Taken together, these findings are consistent with the idea that slow practice is an important tool for musicians when preparing their skills for performance. Of course, as the current data is self-report only, further research is needed to verify if the suggested importance and efficacy of slow practice is reflected in observed practice behaviours, or experimental effects of practising on learning. Nonetheless, these findings provide a starting point for further understanding slowness in music performance preparation.

6.2.2 Multifunctionality of Slow Practice

The current research indicates that slow practice may serve multiple learning functions. For example, ratings of how often different goals of slow practice were employed suggest that both technical and expressive goals are frequently adopted. Building on this initial result, qualitative analysis identified four main functions of slow practice as managing information load, regulating the performer's emotional, mental, or perceptual state, building a foundation for motor learning, and supporting creative and critical problem solving. This again highlights the multiple ways in which slow practice might support music learning. Furthermore, the fact that slow practice appeared to be frequently used at different levels of expertise indicates that slow practice may serve both basic music learning goals, and more advanced purposes. This is in line with previous findings that slow practice was used, not only for basic musical goals, but also for expressive-interpretative purposes by expert musicians (Chaffin et al., 2003). These findings implicate slow practice as a useful and flexible technique to support performance preparation.

6.2.3 Mechanisms of Slow Practice

Moving one step further from the different goals and functions that slow practice may support, the current research also provides some initial insight into possible cognitive mechanisms behind slow music practice. First, musical self-regulated learning (Ritchie & Williamon, 2013) was found to be positively associated with using slow practice. This may indicate self-regulatory processes as one mechanism through which slow practice may support learning. Indeed, this idea is reflected in the current qualitative findings that slow practice may help learners to regulate their emotional, mental, and perceptual states in order to better enjoy and focus on their practice, or to allow them to perceive their playing in new ways. However, the direction of the relationship between self-regulation and slow practice is not known, and rather than supporting self-regulation processes, slow practice may simply require self-regulatory skills. Further research is needed to better understand this relationship.

Qualitative results further supported the idea that slow practice operates on mechanisms of cognitive load management (Owens & Sweller, 2008), by providing examples of musicians using slow practice to make tasks easier (reducing extraneous cognitive load), and to focus more on details (stimulating germane cognitive load). This mechanism should be further tested experimentally, to determine how slowness impacts cognitive load, before firm conclusions are drawn. Nevertheless, it seems that cognitive load is a useful framework for considering slow practice. Additionally, findings suggested that flow (Csikszentmihalyi,

1990) may be a mechanism of slow practice, evidencing descriptions of slow practice as supporting mindful presence in the moment, and positive emotional states. As flow may boost motivation for learning and support the learner's wellbeing (Lee, 2012), further research on the relationship between experienced flow and slowness in practice could be worthwhile.

6.2.4 Individual Differences in Slow Practice Use

Music practice is an individualised activity, which may be adapted to suit the needs of different learners. The current findings similarly indicate how use, and efficacy, of slow practice may depend on individual differences. For instance, it was shown that the relationship between preparatory slow practice (using slow practice as a warm-up or to calm the nerves before a performance), self-regulated learning, and expertise was different between classical and non-classical musicians. While this type of slow practice was positively associated with expertise and self-regulated learning in classical musicians, no such relationships were found in non-classical musicians. This indicates that the ingredients of highly expert practice, and highly self-regulated practice may differ depending on the music performance genre of the musician. For example, in classical music, using slow practice to warm-up may be considered important and used more among experts, while this aspect of practice may not be so highly regarded in, for example, folk or pop music. Further research on how musicians from different performance genres use slow practice would shed more light on this topic.

Similarly, it was found that a few respondents had very negative views on slow practice, viewing it as unproductive and unenjoyable. This minority of respondents highlight that slow practice may not have the same beneficial outcomes for all musicians. While some may find slow practice relaxing and confidence-building, others may find it boring and frustrating. Further, results also showed that the perceived efficacy of particular aspects of slow practice may be shaped by the perspective of the learner. For instance, slowing the tempo of a piece of music may change the perceived expressive content. For some respondents, this was seen as useful by affording new interpretative ideas, while for others this was seen as unhelpful by removing the music from its intended context. Overall, these findings show that the efficacy and functions of slow music practice may be different for different people. Therefore, rules of slow practice cannot be applied generally to all learners, but rather, individuals must experiment and find their own best ways of working.

Nonetheless, the current work may inform and inspire individuals to try new approaches and find their own individualised ways of best preparing for performance through slow practice.

6.2.5 Specific Tempo-management Practice Techniques

Several interesting results were found regarding specific practice techniques related to slowness and tempo management. For example, it was found that the most common tempo organisation strategy in slow practice was to use a gradually increasing tempo, rather than alternating between two tempi or selecting tempi in a random order. Building on this finding, a more detailed understanding of how tempo may be organised was gained from qualitative analyses, in which respondents described combining gradual tempo increase with alternating tempo so as to keep the final performance tempo in mind. Similarly, it was shown that use of slow practice was more commonly reported compared to chunking or rhythm variation, but further qualitative data demonstrated that these three techniques can be combined in creative practising approaches. Thus, the quantitative findings of Study 3 provided an initial overview of practising habits while qualitative findings from Study 4 added a more detailed picture. These more detailed descriptions of practice techniques indicated specific ways in which biomechanical differences between slow and fast playing may be bridged. In addition, the present findings also indicate that specific ways of practising slowly could be malfunctional or suboptimal. For example, if only slow practice is used, or if music is practised too slowly, learners may become stuck in slow tempi, lack performance confidence, or misunderstand the original context of the music. Thus, it is not only using slow practice that is advised to best support preparation for musical performance, but using slow practice in conjunction with other methods (including fast practice), and always maintaining a clear goal during slow practice.

6.2.6 Slow Practice Conclusions

The current work provides foundational knowledge on the cognitive and psychomotor mechanisms of slow music practice; a topic on which little previous research exists despite the high reported prevalence of slow practice in music educational approaches (e.g., Barry & McArthur, 1994). Individual music practice is the vehicle through which the majority of preparation for performance takes place, and the current research aimed to improve psychological understandings of how skill acquisition occurs through slowness and tempo manipulation during this highly individualised activity. Findings indicate that slow practice is an important aspect of performance preparation, widely employed and viewed as important across various expertise levels and different musical genres. Results further suggest that slow practice is multifunctional, meaning that it may be used to achieve various basic and advanced musical goals, and may serve different cognitive purposes in learning. Furthermore, initial evidence was provided supporting potential underlying mechanisms of slow practice as managing cognitive load during learning (Owens & Sweller, 2008), stimulating or requiring self-regulated learning (Ritchie & Williamon, 2013), and possibly supporting flow states (Csikszentmihalyi, 1990). Finally, insight was provided into specific practice techniques, showing that apparently separate strategies may be combined to best support learning, and that in order to optimise slow practice, it must be used in conjunction with other methods, always keeping clear practice goals and eventual performance intentions in mind.

7 Limitations and Further Directions

Several limitations apply to the current findings. Firstly, there is the question of ecological validity. Studies 1 and 2 consisted of reductionist tasks conducted in an un-realistic laboratory environment, which allowed tight control of experimental conditions. However, these tasks do not represent the richness and complexity of real-life musical performance. To more fully understand FOA effects in the preparatory moments before performance, further research is needed applying FOA to more holistic expressive musical tasks in realistic performing environments. Similarly, Studies 3 and 4 were based on self-report data only, and therefore it is not known how the self-reported behaviour and perspectives may correlate with actual practice habits or the true effects of practice methods on learning. Further research utilising practice observation methods, or experimental testing of certain practice techniques on learning would add valuable knowledge to this topic. In addition, for both topics of FOA and slow music practice, further exploration of individual differences would be useful. For example, the current work did not investigate influences of gender, musical instrument, personality, or professional/amateur status. Another factor which may have influenced the current results is the way in which musical expertise was defined. In studies 1 and 2 the novice violin players were experienced in playing other musical instruments, and results may have been different with participants who had no music training. In Studies 3 and 4 musical expertise was measured on reported years of training, but alternative ways of measuring expertise may have produced differing findings.

All four studies are, of course, limited in their ability to generalise findings, due to the specificity of their samples. Studies 1 and 2 consisted of mainly German undergraduate music students and further research should aim to replicate these results in different samples before findings can be confidently generalised. Respondents from studies 3 and 4 came from a convenience sample consisting of mostly classical string-players which may have biased responses in this direction. It should also be noted that the current research yielded several null-results regarding effects of FOA on different performance parameters, indicating that in a musical context, definitions of how to measure performance outcomes may influence the ability to detect effects on performance. This is another reason as to why replication of these effects would be desirable, and it is hoped that the current research will inform future approaches to more accurately predict how FOA effects will occur in music performance skills.

Finally, a wealth of future directions remain to be explored on the topic of music-performance preparation. In attentional focus research, numerous possibilities exist for measuring performance outcomes in different types of musical task and on different musical instruments, while effects of FOA on skill retention and transfer have still been largely unexplored. On the topic of slow music practice, the findings here may stimulate further research observing slow practice methods in realistic contexts, experimental methods to determine the efficiency of different slow practice techniques, and experiences of slowness during practice relating to flow and self-regulatory processes.

8 Conclusions

This dissertation has provided novel insights into the psychology of preparation for musical performance, informing academic understandings of musical skill-acquisition and motor-control theory, as well as providing knowledge that may be useful for music performance-practice and pedagogy. The current findings suggest two evidence-based strategies for supporting a musician's process of performance preparation. Firstly, the successful performance of motor skills may be supported by directing attention away from internal body movement and towards sensory outcomes of the action, in the moments preceding skill execution. In the current research, these benefits to performance of FOA were shown for two violin-bowing tasks, and further research is needed to extend this effect to different contexts. However, a wealth of previous literature supports the generalisability of this effect (e.g. Atkins, 2017; Duke et al., 2011; Mornell & Wulf, 2019; Wulf, 2013). In the current work, these effects applied even to experienced violinists for a simple sound-production exercise, which emphasises the influence on performance that attentional focus may have, even for well-learned skills. The current findings further suggest that, for complex instrumental sound-production skills, focussing on tactile feedback through the musical instrument may present an optimal FOA, in line with previous suggestions (Stambaugh, 2017). This type of focus may also affect physical aspects of motor control, and increase efficiency of muscle use, similar to previous research on FOA in sports contexts (e.g. Neumann, 2019; Wulf & Dufek, 2009). The potential impact of these effects on musicians' health remain to be investigated, as does the seemingly complex influence of expertise on FOA effects. Nonetheless, findings imply that attentional focus may be a powerful performance tool for musicians. This FOA technique could be applied, for example, in high-pressure moments before a performance begins, or just before a particularly difficult technique is executed. Secondly, the long-term preparation of music may be supported by utilising techniques of slow practice (optimally combined with other practice methods) to achieve specific musical goals. The current results suggest that slowness in music practice may support learning in multifunctional ways, through mechanisms of cognitive load management (Owens & Sweller, 2008), self-regulatory skills (Ritchie & Williamon, 2013), and cultivating necessary conditions for flow experiences (Csikszentmihalyi, 1990). For beginner musicians who struggle to know how to practice, or advanced musicians who find practice unstimulating, opting to include elements of slow, concentrated, goal-oriented practice alongside faster methods may improve this long-term aspect of performance preparation.

Overall, the current findings provide psychological insight into processes of music performance preparation from both the angle of optimising music practice over a long period, and preparing the mind and body for action execution in the moments before performance. The combination of these approaches to performance preparation may support musicians to maximise their full potential. Of course, other aspects of preparation for performance remain to be explored such as long-term cultivation of psychological performance skills, or how commanding stage presence and expressive communication skills may be taught. It is hoped that the findings presented here will stimulate such further research on the psychology of music performance and practice, and will provide a piece of the larger puzzle on how to most effectively support musicians of all ages and stages to fulfil their musical potential on stage.

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Summary (English)

Instrumental musicians spend a great amount of time honing their skills and preparing for performance. However, there remains a lot to be learned about the cognitive and psychomotor mechanisms in preparing for musical performance. This dissertation aimed to investigate psychological processes of optimal preparation for instrumental music performance. To this end, two aspects of performance preparation were investigated. In Studies 1 and 2, the effects of a psychological approach to performance during the preparatory moments before action execution were examined through two experimental studies of attentional-focus effects on motor-skill performance in violin bowing. In Studies 3 and 4, the processes of longer-term preparation for performance through music practice were studied via quantitative and qualitative analyses of an online questionnaire exploring reported use of slowness in music practice.

Studies 1 and 2 investigated the effects on motor skill performance in violin bowing, of verbally administered attentional focus instructions, in novice and experienced violinists. The aim was to test the previously proposed *constrained action hypothesis* (CAH), that performance is impaired under an internal focus of attention (FOA) on body movement, relative to an external FOA on action outcomes. In Study 1, FOA effects on tone production were examined in an open-string bowing-task, and performance outcomes were measured on acoustic features of the sound produced, motion-capture measurements of violin and bow movement, and electromyography of muscle activity in the bowing arm. In Study 2, effects on bow-control skills were assessed in a slow-motion bow-control exercise, with outcome measures of task performance (successes and errors), and electromyography of muscle activity in the bowing arm. For Study 2, a further exploratory analysis explored how performers' conscious thoughts may reflect attentional focus effects. Results from Studies 1 and 2 supported the CAH, indicating that violin bowing skills were generally improved under an external focus on bow-string resistance compared to an internal focus on arm movement. This effect was found in Study 1 for acoustic features of violin sound, efficiency of muscle use, and beginners' violin-sway. In study 2, this effect was shown for experienced players' number of task errors, and all players' reduction of muscle activity. Additionally, Study 1 found that consistency of bow motion was improved when focussing on bow-string resistance compared to focussing on sound, and Study 2 indicated that some aspects of attentional focus effects might be reflected in performers' conscious thoughts. Overall, these findings indicate that FOA in the moments before action execution may impact violin bowing skills, with benefits to performance of focussing externally, on bow-string resistance, compared to focussing internally on arm movement. There were no observed benefits to focussing externally on sound. This suggests the importance to instrumental music performance of tactile sensory feedback. Results further indicate that expertise may influence FOA effects in some, but not all, aspects of performance.

Results from Study 3 showed that use of slow practice was extremely common in both classical and non-classical musicians, while slow practice was frequently employed for both technical and expressive goals. Specific types of slow practice were identified as Technical, Expressive, and Preparatory slow practice, with the former two positively associated with self-regulated learning among both classical and non-classical musicians. Preparatory slow practice was differentially associated with self-regulation and expertise, between classical and non-classical musicians, and there were no main associations of slow practice types with expertise. These findings indicate that slow practice is a common and flexible practice

strategy, with multiple possible functions, and that slow practice use may indicate self-regulated learning. Slow practice also appeared to be used commonly across expertise levels, although this differed depending on music performance genre, suggesting the importance of music practice cultures to definitions of quality music practice.

In Study 4, perceived uses and limitations of slow practice were explored through qualitative thematic analysis. Results identified four perceived functions of slow practice as managing information load, regulating states, building a foundation for motor learning, and supporting creative and critical problem-solving. It is suggested that these functions are underpinned by reduction of extrinsic cognitive load and stimulation of germane cognitive processes, and may support flow experiences. Perceived strategic pitfalls of slow practice were identified as using only slow practice, and choosing a tempo that was too slow, which could lead to various technical-practical and emotional-cognitive malfunctions of slow practice. Finally, reported specific techniques of slow practice suggested that issues of how to bridge slow practice with fast playing may be addressed through creative approaches to tempo-organisation and strategic balancing of slow and fast practice methods.

Taken together, these findings provide novel insight into psychological and psychomotor processes of musical skill-acquisition and performance preparation. Studies 1 and 2 highlight the importance to performance of what a musician thinks about during the key preparatory moments before beginning to play, while Studies 3 and 4 provide insight into the cognitive and motor processes of slow music practice. These findings may inform theoretical understandings of musical skill-acquisition, as well as approaches to music performance practice and pedagogy.

Zusammenfassung (Deutsch)

Instrumentalmusikerinnen und -musiker verbringen viel Zeit damit, an ihren Fähigkeiten zu feilen und sich auf Aufführungen vorzubereiten. Bislang ist allerdings noch wenig über die kognitiven und psychomotorischen Mechanismen bei der Vorbereitung auf Musikaufführungen bekannt. Das Ziel der vorliegenden Dissertation war es, die psychologischen Prozesse einer optimalen Vorbereitung auf instrumentale Musikaufführungen zu beleuchten. Dazu wurden zwei Aspekte der Aufführungsvorbereitung untersucht. In den Studien 1 und 2 wurden die Auswirkungen einer psychologischen Herangehensweise, die in den Vorbereitungsmomenten vor der Ausführung einer Handlung angewandt wird, im Rahmen zweier experimenteller Studien zum Einfluss des Aufmerksamkeitsfokus auf die motorischen Fertigkeiten der Geigenbogenführung beleuchtet. In den Studien 3 und 4 wurden Vorgänge in der Langzeitvorbereitung auf Aufführungen untersucht, indem quantitative und qualitative Analysen zum Einsatz des langsamen Übens mittels eines Online-Fragebogens durchgeführt wurden.

Die Studien 1 und 2 untersuchten die Effekte von verbal erteilten Anweisungen zur Aufmerksamkeitsfokussierung auf die motorischen Fertigkeiten beim Streichen einer Geige bei Anfängerinnen und Anfängern sowie bei erfahrenen Violinistinnen und Violinisten. Ziel war die Prüfung der *constrained action hypothesis* (CAH), wonach die Bewegungsausführung bei einem internen Aufmerksamkeitsfokus (FOA) auf die Körperbewegung im Vergleich zu einem externen FOA auf die Handlungsergebnisse beeinträchtigt ist. In Studie 1 wurden die Effekte des FOA auf die Tonerzeugung untersucht, indem die teilnehmenden Personen eine Aufgabe zur Bogenführung an einer offenen Saite durchführten. Die Ausführungsergebnisse wurden anhand akustischer Merkmale des erzeugten Tons, Motion-Capture-Messungen der Violinen- und Bogenbewegungen sowie einer Elektromyographie der Muskelaktivität im Streicharm gemessen. In Studie 2 wurden die Effekte auf die Fertigkeiten der Bogenführung in einer Zeitlupenübung evaluiert, wobei die Aufgabenausführung (Erfolge und Fehler) sowie die Muskelaktivität des Bogenarms mittels Elektromyographie gemessen wurden. Außerdem befasste sich eine weitere explorative Analyse damit, wie bewusste Überlegungen der ausführenden Personen Auswirkungen des Aufmerksamkeitsfokus widerspiegeln können. Die Ergebnisse der ersten beiden Studien unterstützten die CAH und zeigten, dass die Fertigkeiten der Bogenführung bei einem externen Fokus auf den Widerstand zwischen dem Bogen und der Saite im Vergleich zu einem internen Aufmerksamkeitsfokus auf die Armbewegung verbessert wurden. Dieser Effekt wurde in der ersten Studie anhand der akustischen Merkmale des Violinenklangs, der Effizienz der Muskelaktivität und dem Geigenschwung von Anfängerinnen und Anfängern festgestellt. In der zweiten Studie zeigte sich dieser Effekt bei erfahrenen Spielerinnen und Spielern durch die Anzahl der Fehler und bei allen teilnehmenden Personen durch eine Verringerung der Muskelaktivität. Außerdem wiesen die Ergebnisse in Studie 1 darauf hin, dass sich die Konsistenz der Bogenbewegung verbesserte, wenn sich die Spielerinnen und Spieler auf den Widerstand zwischen dem Bogen und der Saite anstelle auf den Klang fokussierten und Studie 2 deutete darauf hin, dass sich einige Aspekte der Effekte des Aufmerksamkeitsfokus in den bewussten Überlegungen der Spielerinnen und Spieler widerspiegeln können. Insgesamt deuten die Ergebnisse darauf hin, dass der FOA in den Momenten vor der Ausführung der Bewegung die Fertigkeiten der Bogenführung beeinflussen kann, wobei die externe Fokussierung auf den Widerstand zwischen dem Bogen und der Saite im Vergleich zur internen Fokussierung auf die Armbewegung vorteilhaft ist. Vorteile durch die externe Fokussierung auf den Klang konnten nicht festgestellt werden. Dies verweist auf die Wichtigkeit des taktilen Feedbacks für Instrumentalmusikerinnern und -musiker. Die Ergebnisse deuten außerdem darauf hin, dass

die Expertise die Effekte des FOA in einigen, aber nicht allen Leistungsaspekten beeinflussen kann.

Die Ergebnisse von Studie 3 zeigten, dass langsames Üben sowohl bei klassischen als auch bei nicht-klassischen Musikerinnen und Musikern sehr verbreitet war und häufig für technische sowie expressive Übungsziele eingesetzt wurde. Spezifische Arten des langsamen Übens wurden als technisches, expressives, und vorbereitendes langsames Üben identifiziert, wobei die ersten beiden positiv mit selbstreguliertem Lernen unter klassischen und nicht-klassischen Musikerinnen und Musikern assoziiert war. Das vorbereitende langsame Üben wurde von klassischen und nicht-klassischen Musikerinnern und Musikern unterschiedlich mit Selbstregulierung und Expertise in Verbindung gebracht und es konnten keine Zusammenhänge zwischen den Arten des langsamen Übens und der Expertise festgestellt werden. Die Ergebnisse zeigen, dass langsames Üben eine verbreitete und flexible Übungsstrategie mit mehreren möglichen Funktionen ist, und dass der Einsatz von langsamem Üben auf selbstreguliertes Lernen hinweisen kann. Langsames Üben schien auch über alle Kompetenzstufen hinweg häufig verwendet zu werden, obwohl sich dies in Bezug auf die Genres einer Musikdarbietung unterschied, wodurch auf die Bedeutung verschiedener Kulturen des musikalischen Übens bei der Definition eines qualitativ hochwertigen Übens hingewiesen wird.

In Studie 4 wurden die wahrgenommenen Einsatzmöglichkeiten und Einschränkungen des langsamen Übens durch die qualitative Thematische Analyse untersucht. Die Ergebnisse zeigten vier Funktionen des langsamen Übens: Bewältigung von Informationslast, Regulierung von Zuständen, Schaffung einer Grundlage für motorisches Lernen und Unterstützung von kreativen sowie kritischen Lösungsansätzen. Es liegt nahe, dass die Funktionen durch die Reduzierung externer kognitiver Belastung sowie der Stimulation relevanter kognitiver Prozesse unterstützt und Flow-Erfahrungen begünstigt werden können. Als strategische Tücken des langsamen Übens wurden die ausschließliche Verwendung des langsamen Übens und die Wahl eines zu langsamen Tempos genannt, was zu verschiedenen technisch-praktischen und emotional-kognitiven Fehlfunktionen des langsamen Übens führen könnte. Schließlich legen die berichteten spezifischen Techniken des langsamen Übens nahe, dass die Frage, wie sich langsames Üben und schnelles Spielen miteinander verbinden lassen, durch kreative Ansätze zur Tempogestaltung und zur strategischen Ausgewogenheit von langsamen und schnellen Übungsmethoden beantwortet werden kann.

Zusammengefasst liefern diese Ergebnisse neue Einblicke in die psychologischen und psychomotorischen Prozesse beim Erwerb musikalischer Fähigkeiten und der Aufführungsvorbereitung. Die Studien 1 und 2 verdeutlichen, wie wichtig es für die Darbietung ist, worüber ein Musiker oder eine Musikerin in den entscheidenden Vorbereitungsmomenten vor dem Beginn des eigentlichen Spielens nachdenkt, während die Studien 3 und 4 einen Einblick in die kognitiven und motorischen Prozesse des langsamen Übens von Musik liefern. Dies Erkenntnisse können in das theoretische Verständnis über den Erwerb musikalischer Fähigkeiten sowie Ansätze für die musikalische Aufführungspraxis und Musikpädagogik einfließen.

List of Publications and Author Contributions

The following scientific articles are included in this dissertation. For all papers, the first author was the primary contributor to study design, data collection, data pre-processing and analyses, preparation of figures and tables, interpretation of results, and writing of the manuscript. For Study 1, technical support and guidance for collection and analysis of motion capture data was provided by Dr. Birgitta Burger, as well as feedback on the writing of the manuscript. For Studies 1 and 2, student research assistants Bettina Zeidler, Ralph-Andreas Stürzinger, and Sophie Platzer assisted with data collection, participant recruitment, and data pre-processing. Guidance on pre-processing of EMG data was also provided by Bjoern Losekamm from the University of Hamburg Institute for Movement Science. For all studies, Prof. Dr. Clemens Wöllner provided guidance and supervision throughout. All studies were carried out within, and funded by, the ERC funded project SloMo, and were based on initial research questions and preliminary study designs from the project proposal, written by Prof. Dr. Clemens Wöllner. The German translation of the short summary of this dissertation was provided by Mia Kuch.

1 Allingham, E., Burger, B., & Wöllner, C. (2021). Motor performance in violin bowing: Effects of attentional focus on acoustical, physiological and physical parameters of a sound-producing action. *Journal of New Music Research*, *50*(5), 428-446. https://doi.org/10.1080/09298215.2021.1978506

2 Allingham, E., & Wöllner, C. (2021). Effects of attentional focus on motor performance and physiology in a slow-motion violin bow-control task: evidence for the constrained action hypothesis in bowed string technique. *Journal of Research in Music Education*, *70*(2), 168-189. https://doi.org/10.1177/00224294211034735

3 Allingham, E., & Wöllner, C. (2022). Slow practice and tempo management strategies in instrumental music learning: Investigating prevalence and cognitive functions. *Psychology of Music.* Advance online publication. https://doi.org/10.1177/03057356211073481

4 Allingham, E., & Wöllner, C. (2022). Putting practice under the microscope: The perceived uses and limitations of slow instrumental music practice. *Psychology of Music.*

Statutory Declaration/ Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

I hereby declare upon oath that I have written the present dissertation independently and have not used further resources and aids than those stated.

Hamburg, 30.1.22

Stadt, den | City, date

Unterschrift | Signature

Study 1.

Motor performance in violin bowing: Effects of attentional focus on acoustical, physiological, and physical parameters of a sound-producing action.

Emma Allingham, Birgitta Burger, and Clemens Wöllner

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Motor performance in violin bowing: Effects of attentional focus on acoustical, physiological and physical parameters of a sound-producing action

Violin bowing is a specialised sound-producing action, which may be affected by psychological performance techniques. In sport, attentional focus impacts motor performance, but limited evidence for this exists in music. We investigated effects of attentional focus on acoustical, physiological, and physical parameters of violin bowing in experienced and novice violinists. Attentional focus significantly affected spectral centroid, bow contact point consistency, shoulder muscle activity, and novices' violin sway. Performance was most improved when focusing on tactile sensations through the bow (somatic focus), compared to sound (external focus) or arm movement (internal focus). Implications for motor performance theory and pedagogy are discussed.

Keywords: constrained action hypothesis, violin performance, electromyography, motion capture, music information retrieval, tactile feedback

Introduction

The rich, expressive sound of the violin has been described as imitating the quality of the human voice (Deutsch, 2011). Learning to produce this sound requires highly specialised fine motor skills, developed over years of practice (Konczak et al., 2009), and while mathematical understanding of bowed string motion is well documented (e.g. Schoonderwaldt, 2009a), little is known about how psychological performance techniques affect these skills. A human's motor control of a musical instrument exists within a cognitive system involving thoughts and mental processing (Desmet et al., 2012), meaning that a musician's psychological approach to performance may explicitly or implicitly influence their physical manipulation of sound. In sport research, a wealth of studies have found that motor skill performance can be improved by focusing attention on the environmental effects of an action compared to focusing on internal movement processes (for a review see Wulf, 2013), but little is known about these effects in instrumental music making. Violin playing offers a particularly interesting context to explore this topic due to the sophisticated psychomotor skills required for sound manipulation. The current study explores effects of the psychological performance strategy 'focus of attention' (FOA) on the system of sound production in violin playing, by investigating changes in sound quality (acoustical analysis), instrument movement (motion capture), and physiological muscle activity (electromyography).

The Action-sound chain

In describing the process of sound-producing actions, Jensenius (2007) depicted an *action-sound chain* of cognition in which neurological activity in the brain leads to physiological muscle activity, physical movement of limbs, mechanical control of the instrument and eventually acoustical impacts on the environment (Figure 1). In the current study, we investigate how an additional *psychological* element, such as a performance psychology technique, may influence sound production. Thus, the action-sound chain provides us with a useful framework for exploring effects of FOA on violin sound production. We investigate effects of differing attentional foci on physiological, physical and acoustical aspects of violin tone production, measured respectively through electromyography of muscle activity in the bowing arm, motion parameters of the violin and bow, and computationally extracted timbral features of sound.

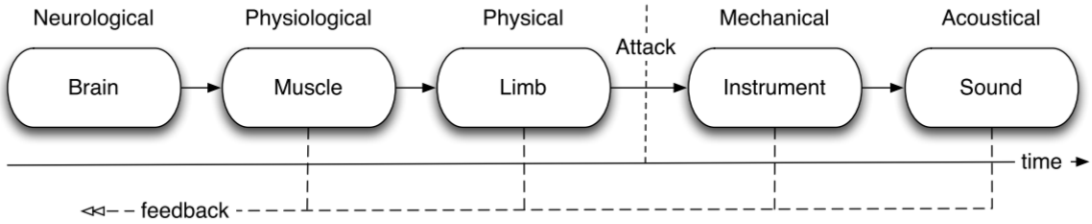

Figure 1. Action-sound chain as depicted by Jensenius (2007).

Acoustic features of violin sound

Defining acoustic parameters to measure tone quality can be a complex endeavour. Perceptions of musical timbre are complex and multifaceted (e.g. Alluri & Toiviainen, 2009), and in terms of violin sound, the challenge of providing quantifiable acoustic measures of tone quality is considerable (Giraldo et al., 2019). Nonetheless, acoustic features of string sound can provide information about the means of sound production. For example, the root mean square (RMS) of an audio signal provides a measure of overall energy in the sound wave, and is calculated by squaring, averaging, and then taking the square root of the signal amplitude (Lartillot & Toiviainen, 2007). The RMS of an audio signal is commonly considered to provide information about the loudness of the sound (Hove et al., 2019). Roughness is another acoustic feature, which gives a measure of sensory dissonance (Eerola et al., 2012), or the "noisiness" of a tone (Liew et al., 2018). The perception of roughness is caused by the phenomenon of 'beating' between sinusoids, which can originate from harmonic dissonance between two tones, or, as is relevant to the current study, timbral dissonance (Sethares, 2005), within an individual tone. As roughness has been associated with perceived unpleasantness (Liew et al., 2018), we might expect higher roughness to indicate lower quality of violin tone. A third acoustic feature widely considered to be an important aspect of timbre perception is spectral centroid which is a mathematical measure of the geometric centre of the distribution of a sound wave's spectrum (Lartillot & Toiviainen, 2007). Spectral centroid can be considered a measure of the perceptual "brightness" of tone (Edgerton et al., 2014; Schoonderwaldt, 2009b), and as violins with higher brightness have been judged as better quality by experts (Łukasik, 2005), a higher spectral centroid might indicate better quality violin tone.

Physical and physiological aspects of violin bowing

In physical terms, sound production on the violin is controlled via three main parameters: bow speed, bow force (downward pressure on the string), and the distance between the bow's position of contact with the string and the violin bridge (i.e., bow contact point, Perez-Carrillo, 2016; Schoonderwaldt, 2009b). Within this dynamic system of sound creation, violinists manipulate these parameters to achieve artistic expression, while simultaneously maintaining a delicate balance between parameters to maintain tone quality. Thus, subtle alterations to bowing variables can affect the sound produced. For example, it has been shown that the spectral centroid of a violin tone is mainly controlled through bow force (Schoonderwaldt, 2009b), while volume of playing tends to be controlled through bow contact point. Optical motion capture technology can be used to measure aspects of bow control as motor performance outcomes at the physical stage of sound production. Kinematic parameters of bow velocity and acceleration, as well as positional information of bow contact point provide information about the performer's approach to sound production, as well as their spatial and temporal motor control abilities. For example, a fundamental technical skill in learning to use the violin bow is the ability to keep the bow parallel with the violin bridge, which can be measured through consistency of bow contact point.

A violinist's mechanisms of bow control are situated within the musician's whole body, therefore it is considered important that the whole body is able to move freely so that stiffness and excess muscle tension are avoided (Medoff, 1999; Roos, 2001). For example, in cello playing, head and torso movements contribute to the player's ability to generate fluid bowing and good quality sound (Rozé et al., 2020). This finding highlights how overall freedom of body motion might impact sound quality. Thus, a measure of whole-body motion such as instrument sway may be considered an important global aspect of the physical stage of a sound-production. Furthermore, more static postures have been found to be associated with increased pain, while increases in micro movements are associated with less pain (Vergara & Page, 2002), indicating that postures which are "too still" may negatively impact the body.

In addition, the physiological stage of sound production can be investigated using electromyography (EMG), which measures small electrical currents in muscles, caused by muscle contraction (Reaz et al., 2006). EMG muscle activity can provide information about energy expended through muscle use - another important aspect of the motor control system. Excess muscle tension is a common health issue among instrumental musicians (Burkholder & Brandfonbrener, 2004), and something that somatic training methods aim to reduce. Exploring how attentional focus may affect global motor behaviour and muscle activity will provide a wider picture of how psychological performance strategies can affect different aspects of a sound production task.

Focus of attention in motor skill performance

In order to explore how a change in psychological approach might affect the system of sound production, the field of sports performance psychology provides an appropriate paradigm. Research on the topic of focus of attention (FOA) in sport has shown that the object of a performer's thoughts can affect their motor performance. In this paradigm, performers are given verbal instructions as to which aspect of a motor action they should think about while performing. Types of FOA have been categorised as either "internal" (focusing on the internal body movements required to perform the task), or "external" (focusing on the effect of the task in the external environment, Wulf & Lewthwaite, 2016). An internal focus instruction directs attention within the body (and must explicitly refer to the body, e.g., "focus on your arm"), while an external focus instruction directs attention outside of the body (and must not explicitly refer to the body, e.g. "focus on the sound" Wulf, 2013). Results widely show that an external focus produces superior performance for many types of gross motor skill (e.g. Neumann, 2019; Wulf, 2013). This phenomenon is explained by the *constrained action hypothesis* (CAH, McNevin et al., 2002; Wulf, McNevin, & Shea, 2001) which states that an internal focus brings conscious attention to automatic movement mechanisms which would normally operate at the implicit level, disrupting automaticity and leading to impaired motor performance.

Building on the differential effects of internal and external foci, some studies have also shown a *distance effect* such that external foci further from the body (e.g., on a point in the distance) produce superior performance compared to external foci closer to the body (e.g., on a piece of equipment, Alishah, Ates, & Ahmadi, 2017; Bell & Hardy, 2009; McKay & Wulf, 2012; McNevin, Shea, & Wulf, 2002; Porter, Anton, & Wu, 2012; Singh & Wulf, 2020). This shows that, in addition to differential effects of internal vs external foci, various types of external foci may differently affect performance. Furthermore, an internal focus can produce measurable changes to motor behaviours such as less efficient muscle use (Vance et al., 2004), and changes to aspects of physical motion (Wulf & Dufek, 2009). These findings exemplify how a seemingly small change in psychological approach can impact both performance of a specific motor task, and measurable changes to the global motor control system.

Attentional focus in music

A few previous studies have laid important groundwork for understanding FOA effects in music making. Duke, Cash, and Allen (2011) found an effect of attentional focus on skill transfer in a piano task, such that temporal evenness of playing two alternating notes was improved by focusing on either sound or the piano hammers (distal external foci), compared to the piano keys (proximal external focus) or the fingers (internal focus). These results were seminal in supporting the CAH for a musical task involving auditory feedback. Similarly, Atkins (2017) found that trained singers received higher expert ratings when performing under distal external foci compared to internal and proximal external foci, while Mornell and Wulf (2019) found that an external focus on musical expression compared to an internal focus on technical accuracy improved expert ratings of both musicality and technical accuracy for various kinds of expert instrumentalists.

On the other hand, some music studies have failed to replicate the FOA effects found in sport. Atkins (2013) found a main effect of FOA on expert ratings of untrained singers' performances, but differences between the conditions were unclear. Contrary to the CAH, performances were most often ranked as best under an internal focus on feeling vibrations in the zygomatic arch (cheekbones), compared to feeling vibrations in the throat, focusing on a microphone, or focusing on a distal point on the wall. In this study, Atkins notes that the internal focus instructions introduced extra tactile sensory feedback (i.e., feeling vibrations in the body) rather than purely focusing on movement itself, and this aspect of the internal foci may have affected results. Indeed, the zygomatic arch focus might actually be considered an external focus, as it diverted attention away from the main source of motor activity (the larynx), and focused not on movement, but on tactile sensation. Similarly, two studies on woodwind playing also failed to support the CAH, with no significant effects of focus condition on performance outcomes (Stambaugh, 2017, 2019). Stambaugh likewise suggests that as tactile sensory feedback plays an important role in controlling sound production in woodwind playing, any attention to tactile sensations brought about as a consequence of the internal focus instructions might have interfered with constrained action effects. Tactile sensory feedback refers to afferent touch sense information such as vibrations or pressure controlled by an efferent action, therefore providing guiding information for the control of that action. In instrumental music making, tactile sensory feedback might constitute feeling vibrations from the instrument, or changes in pressure or resistance depending on how the fingers interact with the instrument. It is also noted that basic sound production using woodwind instruments is more complex (i.e., involves coordination of both hands and breathing) than previously tested tasks of piano playing and singing, which also may have affected results (Stambaugh, 2017). Although Mornell and Wulf (2019) found support for the CAH in a variety of instrumental performances, their conception of the external focus as "on musical expression" and the internal focus as "on technical accuracy" is not directly comparable with the other studies discussed here. Therefore, the current literature on FOA in music making is lacking in evidence for the CAH in complex instrumental sound production. Furthermore, the potential influence of bringing attention to tactile feedback in instrumental playing warrants further exploration, as does the study of measurable motor outcomes such as muscle activity and motion features.

Tactile sensory awareness in music performance

In support of indications from previous FOA research in music that attention to tactile sensory feedback may be beneficial to performance, other areas of research similarly highlight the role of attention to body sensations. For example, somatic training methods such as the Alexander technique, Feldenkrais method, and body mapping are widely thought to improve performance and reduce risk of injury through the cultivation of sensitivity to body sensations, muscle tension and movement habits (Davies, 2020; Lee, 2018; Slade et al., 2020). While some academics have argued that this somatic approach contradicts CAH theory because it focuses attention within the body, and on process rather than outcome (Ives, 2003; Shusterman, 2009), it has also been argued that the somatic approach in fact encourages external FOA, by focusing on quality of movement, rather than movement itself (Mattes, 2016). In support of the somatic approach, studies have found that expert performers under pressure tend to focus on physical sensations such as breathing or posture (Buma et al., 2015; Kokotsaki & Davidson, 2003), and that attention to body sensations may play a role in preventing overuse injuries (Batson, 2007). As mentioned before, research has highlighted the importance to learning of tactile feedback for woodwind and brass players (Stambaugh, 2017, 2019), while string playing pedagogy also indicates the value of developing kinaesthetic sensing (i.e., awareness of body posture, movement, strength etc.), which is closely connected with tactile sensing, in cultivating good playing technique (Cotik, 2019). Therefore, attention to tactile feedback may influence production of sound in string playing. To our knowledge, no previous study of FOA in music performance has investigated how focusing on tactile sensory feedback through an instrument might compare with internal and more distal external FOA.

Expertise and FOA

FOA research in sport has shown that the CAH applies to performers of various levels of expertise (Wulf, 2013). However, in a recent study it was shown that beginner volleyball players may benefit more from a proximal external focus (i.e., external to, but close to the body), and experts from a distal one (Singh & Wulf, 2020). The authors suggest that their proximal external focus which utilised *imagery* about arm angle without referencing arm movement per se, avoided constrained action by diverting attention away from motor mechanics, while also bringing awareness to action-execution technique. While experts were able to achieve their best performance by focusing distally on a target, beginners benefitted from the extra attention to technical detail allowed by the proximal external focus.

In musical tasks, interactions of FOA with expertise remain unclear. Atkins (2017) found beneficial effects of an external focus for trained singers, while Atkins (2013) found benefits of both external and internal foci for untrained singers. In contrast, Duke, Cash, and Allen (2013) found that less experienced pianists benefitted from a more external FOA, while expert pianists were unaffected. Violin bowing is a particularly complex motor skill, which beginners must accumulate at least 700 hours of practice to achieve (Konczak et al., 2009). Thus, violin bowing is a particularly interesting context for exploring effects of FOA and expertise.

In summary, sound production in violin playing is relatively well understood in terms of the mathematical relationships between bowing parameters and string motion, but little research exists on how psychological performance techniques may influence bowing action. A useful cognitive framework, the sound-producing action chain (Jensenius, 2007) depicts the various stages of sound production from neurological to acoustical, and we suggest that the additional *psychological* element should be explored. In sports research, such a psychological effect on motor performance has been observed in research on attentional focus. That is, motor performance is improved by adopting an external focus on task goals compared to an internal focus on movement processes (Wulf, 2013), a phenomenon explained by the *Constrained Action Hypothesis* (CAH) (McNevin et al., 2002; Wulf, McNevin, & Shea, 2001). Further, this constrained action effect has been shown to influence other aspects of the motor system such as motion features, and muscle activity (Vance et al., 2004; Wulf & Dufek, 2009). However, evidence for these effects in music performance is limited. In addition, some evidence suggests that attention to tactile sensory feedback could be beneficial in instrumental music making (Davies, 2020; Lee, 2018; Slade et al., 2020; Stambaugh, 2017), which may have implications for finding an optimal focus of attention for music performance.

The Current Study

The current study aimed to investigate how a psychological performance approach might affect motor skill performance during violin tone production. To this end, we applied the FOA paradigm founded in sports psychology to a simple violin sound production task, for both experienced players and complete novices. The selection of complete novices (i.e., participants with no prior string playing experience) was intended to create a high contrast in expertise between the two groups. For beginners, this early stage of learning is of great pedagogical importance, where teachers must take care to instil good technique to avoid the need for correction of bad habits later (Salzberg & Salzberg, 1981), while for experienced players, returning to basic technique such as open-string bowing is useful for maintenance of good playing technique. To gain a detailed view of effects on the motor system we examined outcomes at various stages of the sound-producing action chain (see Figure 1), namely physiological (EMG muscle activity), physical (technical bowing and scroll sway motion parameters) and acoustical (computationally extracted timbral features of the sound produced). While scroll sway may not be a direct physical aspect of sound production, it is considered here as part of the sound-producing action chain as whole-body motion may influence production and perceptions of sound (see Introduction).

We aimed to compare effects of internal and external foci with a novel "somatic" focus which aimed to bring awareness to tactile sensory feedback through the bow. The internal instruction aimed to bring attention to the internal mechanics of the task (arm movements), and the external instruction aimed to bring attention to the external goal of sound production. The somatic focus aimed to direct attention towards tactile sensations resulting from the action (i.e., feedback), through reference to the musical instrument. For this condition, performers were instructed to focus on “the resistance of the bow against the string” with the reasoning that doing so would draw attention to tactile feedback from the bow such as vibrations and changes in tension. We considered this instruction to be the most naturalistic and straightforward way of achieving such a focus without introducing confounds between the different focus instructions (for example, number of words or degree of complexity of the instruction), the methodological importance of which has been discussed (Wulf, 2013). In this way, the somatic focus was intended to provide a focus grounded in bodily awareness through attending to fluctuations in touch sensations of the fingers on the bow, paralleling the kind of awareness which may occur as part of somatic training methods. This focus can be considered a type of external focus, as it does not refer directly to body movement (Wulf, 2013). The focus instruction details are displayed in Table 1.

Table 1. Focus instruction details

Focus condition	Verbal instruction	Description	References to focus concept
Internal	Focus your attention on the movement in your right arm.	Directs attention to internal movement mechanisms and refers directly to the body.	(Stambaugh, 2019; Wulf, 2013)
External	Focus your attention on the sound you produce	Directs attention to the environmental effects of the action. Does not refer directly to the body.	(Duke et al., 2011; Stambaugh, 2019; Wulf, 2013)
Somatic	Focus your attention on the resistance of the bow against the string	A type of external focus as it directs attention towards the musical instrument, and does not refer directly to the body. Aims to bring attention to tactile feedback through the instrument.	(Duke et al., 2011; Mattes, 2016; Wulf, 2013)

We hypothesised that:

1) Focus instructions would affect motor control of sound production at physiological, physical, and acoustical stages. In accordance with the constrained action hypothesis, we predicted that external and somatic foci would benefit motor performance relative to the internal focus. As a somatic focus has not been tested before in this context, we did not predict differences between somatic and external.
2) There would be differences in performance outcomes and attentional focus effects between novices and experts.

The physiological, physical and acoustical stages of sound production were measured through surface EMG sensors, optical motion capture, and music information retrieval, respectively.

Materials and Methods

Participants

Thirty-three right-handed participants (18 female, mean age = 24.97 years, *SD* = 4.80) were recruited. One participant was excluded from the analysis as their level of training was not enough to be considered experienced, but too much to be considered a novice. This resulted in a sample of 32 participants (18 female, mean age = 24.94, *SD* = 4.87), all of whom were compensated €10 for taking part. All participants played a musical instrument (mean years played = 15.20*, SD = 6.35*). 16 participants comprised the novice group, having never played a string instrument before, and 16 qualified as experienced violin or viola players, having at least 7 years of training in their instrument. The novice participants were specifically required to have experience playing a non-string instrument, to ensure that they possessed basic musical spatial-temporal skills that would equip them for the task of learning foundational violin technique in a short training session.

Equipment and experimental set-up

The experiment was carried out in a 5m x 5m room outfitted with eight infrared-based motion capture cameras (Qualisys Oqus). All participants used the same violin, which was a Fastoso intermediate model which was mounted with an AKG Harman C411PP contact microphone. Red stickers were placed on the stick of the bow to mark the middle section of the bow. The sound was recorded via Audio Desk software and a MOTU 828MK3 audio interface, while motion capture data was recorded via Qualisys Track Manager (QTM) software. Audio and motion capture were synchronised via SMPTE timecode. Five reflective markers were placed on the violin and bow, as shown by the black markers in Figure 2 (right panel), from which we later derived position and motion data. Motion data of participants' bodies was also collected, although it is not analysed in the current study. Therefore, it should be noted that participants wore motion capture jackets and caps during the experiment. The jackets were made of soft, flexible material, designed to allow considerable freedom of movement for studying wide ranges of motion, therefore the jackets did not restrict performers' motion in the current study.

Trigno Delsys wireless surface EMG sensors recorded muscle activity using QTM software in synchrony with the motion capture. The wireless EMG sensors were placed on the participant's bicep, tricep, and deltoid muscles of the right arm (see Figure 2, left panel) and secured with strong adhesive Delsys stickers, prior to fitting the motion capture jacket. Care was taken to ensure EMG sensors were not disturbed by the jackets, through checking sensor position and the EMG signal. All fitting of equipment and placing of sensors and markers was carried out by the first author.

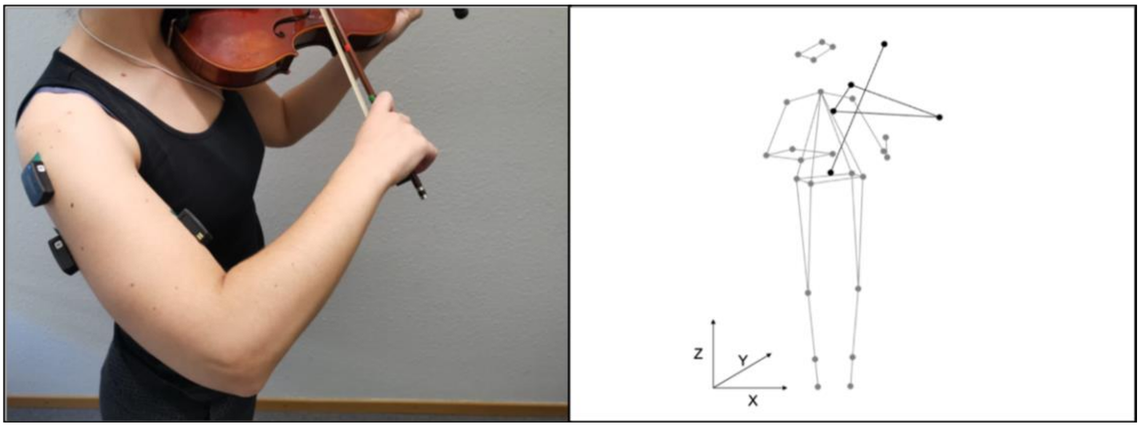

Figure 2. The left panel shows placement of EMG sensors on the bicep, tricep (long muscle head) and deltoid (medial muscle-head) muscles. The right panel shows motion capture markers placed on the participant's body, violin, and bow, with X, Y and Z axes depicted in the bottom left corner.

Procedure

Before the start of the experiment, participants gave written informed consent in accordance with the Local Ethics Committee guidelines, and filled out a brief demographic questionnaire including their musical training history. Next, EMG sensors were positioned over the belly of the muscle, parallel to muscle fibres, in accordance with SENIAM guidelines (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles, see www.seniam.org). The signal to noise ratio was then visually checked for each muscle using the SENIAM recommended movements. Next, participants were outfitted with the motion capture jacket, cap, and markers, and there was a short training session in which novices were taught the basics of holding the violin and bow and how to carry out the experimental tasks (see below), while experienced violinists were simply taught the experimental tasks. This training was led by the first author who is an experienced violin teacher, and care was taken to ensure that basic bowing technique was adequately established. For novices, this session lasted approximately 15 - 20 minutes, and for experienced violinists, approximately 10 minutes. Participants were instructed to keep their visual gaze on the violin A-string during the task.

Participants performed 4 bows (starting on a down-bow) on the open A-string (tuned to A4) in response to a metronome, set to 30 beats per minute (IOI = 2000 milliseconds (ms)). Participants were instructed that the goals of the task were: 1) to play in time with the metronome, 2) to use the middle section of the bow as defined by the stickers, and 3) to play with a good sound. A good sound was defined as: 1) consistent volume and tone quality, 2) avoiding scratching, scraping or squeaking sounds, 3) smooth bow changes. They were instructed to create a resonant tone at a medium *mezzo-forte* dynamic.

In an initial practice round, participants carried out the task with no focus instruction. The task was then performed under three focus conditions, counterbalanced in order across participants: internal focus, external focus, and somatic focus. For each condition, participants performed three trials of the task. Before each new focus condition, participants sat quietly for one minute to minimise carry-over effects between conditions. Focus instructions were given verbally, and reinforced for each repetition of the task. After each focus condition, participants were asked to verbally report what they had been thinking about, to provide an indication of how well focus instructions were followed. After the experiment was complete, participants were debriefed about the purpose of the experiment.

Data Analysis

Ability to follow the focus instruction

One methodological issue with the FOA paradigm is that it is difficult to know if participants followed the focus instructions. Most FOA studies simply assume that instructions are followed correctly. Therefore, to provide an indication of how well participants followed the focus instructions we inspected the reported thoughts after each condition. The data consisted of one comment for each condition (3 comments) per participant, yielding 96 comments in total. Participants' answers were transcribed by the experimenter and later were coded by the first author as either providing evidence that the instruction was followed (1) or not (0). Comments were coded with a 1 if the participant reported: a) that they were thinking about the object of the focus instruction or that they were thinking about "the focus", or b) if they directly reported being able to do the focus, enjoying the focus or trying to do the focus. Comments were coded with a 0 if participants a) directly reported difficulty with the focus instruction or b) if their reported thoughts were completely irrelevant to the focus, implying distraction. The purpose of this analysis was to provide an overall indication of how well focus instructions were followed, but not to provide criteria for judging individual participants. For example, because this data is limited in its' ability to truly asses the degree to which a person focuses on a certain object, we do not use these data as a basis for exclusion or further analysis. Also, even though a participant might have exhibited difficulties following the focus instructions, they may have still been affected by the instructions at an implicit level. 93% of the overall comments were coded with a 1, indicating a high rate of success. Overall, 5 participants received a 0 code for one condition out of three, and 1 participant received a 0 for two conditions. No participant received a score of 0 for all three conditions.

Tempo and bow speed checks

The bowing task conditions were devised so as to control, across focus conditions, for tempo (by indicating the tempo with a metronome) and speed of bow used (by indicating amount of bow to be used with stickers on the bow). However, participants may have deviated from the intended parameters. Therefore, to check that there were no systematic deviations of these variables across focus conditions which might influence results, we ran mixed ANOVAs on the outcome variables 'length of task' (i.e., mean time taken to complete a trial), and bow velocity. The within-participants factor was condition, and the between-participants factor was expertise. Effects of Focus Condition and Expertise are displayed in Table 2. There were no significant interaction effects.

Table 2. Effects of Focus Condition and Expertise on length of task and bow velocity

	F value	P value	η^2_p
Length of task			
Effect of condition	0.53(1.32,39.62)	.521	.02
Effect of expertise	3.64(1,30)	.066	.11
Bow velocity			
Effect of condition	1.04 (1.60,47.86)	.348	.03
Effect of expertise	1.58(1,30)	.218	.05

* Mauchley's test of sphericity was significant ($p < .001$) for both measures, so the Greenhouse-Geisser corrections are reported

As there was no significant difference in these variables between focus conditions, we deemed it unnecessary to further statistically control for length of task or speed of bow in the rest of the analyses. Regarding small deviations in length of recordings, many of the outcome variables are expressed as mean or standard deviation values over time, meaning that small variations in length should not affect results.

Audio

Audio files were first segmented using SMPTE timecode to match the time series of the motion capture recordings. Audio was then processed using the MIR (Music Information retrieval) toolbox (Lartillot & Toiviainen, 2007) and custom code in MATLAB software. Each audio clip was trimmed from the start to the end of the audio waveform to exclude silence. All trials were visually inspected for signal quality, and 16 trials (4.6% of total trials) were excluded from the analysis due to pops/cracks in the audio signal. If more than two trials per condition were deemed poor quality, the participant was excluded completely from the analysis. Two participants were fully excluded on this basis, and an additional participant was excluded because the original audio files were lost. This resulted in a total of 29 participants for the audio analysis.

Segmentation of the audio signal. In order to assess tone quality on the steady part of the sound without the bow changes, we segmented the audio into "bow" and "bow change" sections. The locations of bow changes were detected using the *MIRpeaks* function, which identifies the time points at which an audio signal peaks or troughs. In this case, identifying the troughs in the signal revealed the time at which the bow changed direction. Visual inspection and parameter adjustments for each recording ensured that these time points were correctly identified. The "bow change" sections comprised a window around the bow change (defined as 20% of the length of the previous bow), and "bow" sections consisted of the rest of the signal. Therefore, the size of the bow change window applied was not the same across recordings, but was adjusted based on the individual timing of each bow. This allowed a fair analysis, ensuring that the bow change sections represented consistent proportions of each recording. For example, if one recording was performed slightly quicker than another, the bow change window would be smaller to more accurately represent the time in which the bow change took place. The percentage size of the window was chosen based on a visual inspection of the data and was deemed to be an appropriate window size. A segmentation example is displayed in Figure 3. MIR features were then applied only to the "bow" sections, to give an indication of the quality of the sound regardless of the bow changes.

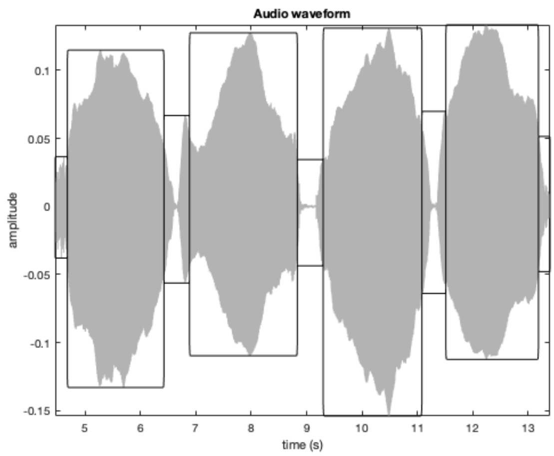

Figure 3. Segmentation of audio waveform into “bow” (larger sections) and “bow change” (smaller sections) segments.

MIR (Music Information Retrieval) features. Based on previous literature, we selected three MIR features to measure acoustic qualities of the sound produced during the task (see Table 3): spectral centroid, roughness, and RMS (see Introduction for detailed descriptions). While these three measures are not exhaustive of the possible changes to tone quality which could occur, they were considered to be the most relevant, easily interpretable acoustic features to violin sound production technique. For further details of feature derivation see the MIR Toolbox manual (Lartillot & Toiviainen, 2007). Each feature was derived using a windowed analysis (window length = 25ms, overlap = 12.5ms), from which the mean and standard deviation over time were calculated.

Table 3. List of MIR features used to represent changes in tone quality

Feature	Description	Explanation	References
Spectral centroid	Measure of the gravitational centre of the spectral distribution of a sound	Associated with perceived brightness, and bow pressure in violin playing	(Edgerton et al., 2014; Schoonderwaldt, 2009b)
Roughness	Measure of sensory dissonance caused by the “beating” of two sinusoids in the same critical band	An estimate of sensory dissonance	(Eerola et al., 2012)
RMS	Root mean square of amplitude, measure of the energy of the signal	A rough measure of the loudness of a sound	(Hove et al., 2019)

Motion Capture

In QTM software, data were labelled and trimmed via a visual inspection from the start to the end of the bowing action. Finishing gestures at the end of bowing were excluded, as the aim was to examine the kinematics of technical bow movements during sound production. Gaps were filled in QTM using either linear interpolation, or the relational gap-fill method, which employed linear interpolation within a local coordinate system defined by the available violin markers. Most gaps were less than 10 frames (0.05ms) long, and the maximum filled gap was 75 frames (0.38ms) long. All gaps were carefully visually inspected to ensure appropriate gap filling, and any trials with too much missing data were excluded from analysis (see below). The violin scroll marker was used to indicate instrument sway, while technical aspects of sound production were derived from the bow markers. Data were then processed in MATLAB using the Motion Capture Toolbox (Burger & Toiviainen, 2013). For analysis of the bow, data were converted to a local co-ordinate system in which data were expressed in relation to the violin with the X-axis parallel to the violin bridge (see Figure 4), and the origin positioned at the lower left corner of the violin. This controlled for movement of the violin and individual height differences. For analysis of bow motion, two secondary markers were created by averaging the two bow markers to create a mid-bow marker, and averaging the two markers at the lower bout of the violin to create a "mid-base" marker, which served as a reference for the bow contact point measure (see below). One participant was excluded from the scroll sway analysis due to a completely missing scroll marker in their motion data. From the bow measures, two trials (from two separate participants, 0.6% excluded trials) were excluded due to poor quality recordings (i.e., missing trajectories).

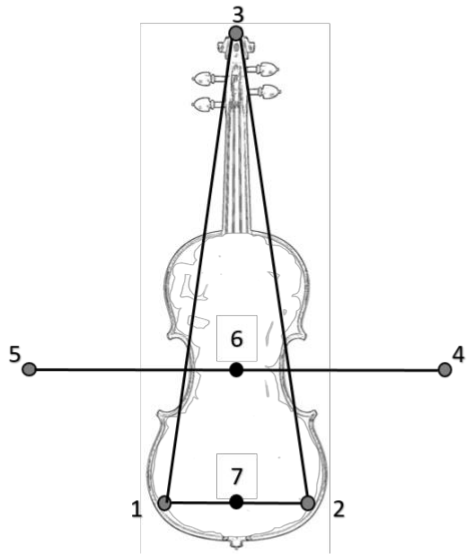

Figure 4. Motion capture violin markers. The grey markers indicate the physical markers placed on the violin and bow, and the black markers indicate the "virtual" markers used for bow analysis. The markers are: 1) left base, 2) right base, 3) scroll, 4) bow heel, 5) bow point, 6) bow mid, 7) mid base.

Bow contact point

The contact point of the bow refers to the bow's positioning on the string relative to the bridge. We calculated mean contact point as the difference between the mean position of the mid-bow in the Y-dimension (i.e., perpendicular to the violin bridge), and the mean position of the mid-base in the Y-dimension, in millimetres (mm). Smaller values represent playing closer to the bridge, and bigger values further from the bridge. Consistency of contact point was calculated as the standard deviation of the position of the mid-bow in the Y-dimension.

Scroll sway (freedom of motion)

We calculated scroll sway in the medio-lateral axis (mm), as a measure of freedom of overall body motion. Scroll sway was operationalised as the standard deviation of the scroll marker position data in the Y axis. This approach to deriving sway has been used successfully in previous research on body sway (i.e Riley, Stoffregen, Grocki, &

Turvey, 1999). Scroll sway was derived from the global coordinate system to represent a wider range of motion including both upper body and violin motion. As the measure used was standard deviation of position data, individual differences in the angle of the violin to the body would not influence the measure. Similarly, as only Y axis information was used, differences in participant height or arm length would also not affect the measure.

Bow acceleration

Acceleration of the bow was derived from the three-dimensional position data, in millimetres per second squared (mm/s^2) and then the Euclidean norm was derived to provide one value across three dimensions. These values were then averaged over time.

Electromyography

EMG data were band-pass filtered at 20-450Hz within the wireless sensor, and further processed using custom software in MATLAB. All data were visually inspected, and 4 trials containing large artefacts were excluded from the analysis (0.3% total excluded trials), although no participants had more than one trial per condition excluded. Data were mean centred and full-wave rectified. A moving RMS filter was applied with a window of 50ms and overlap of 25ms, and data was normalised (max-min) to control for individual differences. The mean RMS value was then calculated in millivolts (mV), to represent the power of muscle activity during each trial, and values were averaged across trials.

Statistical Analysis

All variables were screened for outliers such that values higher or lower than three standard deviations from the mean were excluded. Total outlier exclusions were 0.02% of MIR data, 0.01% motion capture data, and 0.01% EMG data. For each dependent variable, a mixed analysis of variance (ANOVA) was carried out with within-participants factor 'Focus Condition' (3) and between-participants factor 'Expertise' (2). To test for the parametric assumption of normally distributed model residuals, the distributions of all ANOVA residuals were checked through visual inspection and Shapiro-Wilk test for normality. One residual appeared to deviate from a normal distribution (*SD* bow acceleration), However, as the F-test has proved to be largely robust to violations of the normality assumption (Blanca et al., 2017; Kozak & Piepho, 2018), this should not be considered a major problem to the interpretation of this result. All other parametric assumptions were satisfied. For all tests, alpha threshold of statistical significance was set at .05. Where Mauchley's test of sphericity was violated, the Greenhouse-Geisser corrected degrees of freedom are reported. To follow up significant main effects of focus condition, Bonferroni-corrected post-hoc pairwise comparisons were conducted. To follow up interaction effects of condition with expertise, simple effects analyses were carried out, testing for effect of condition in each expertise group separately.

Results

Acoustic features

For mean spectral centroid, a main effect of Focus Condition was found ($F(1.52,38) = 3.65$, $p = .047$, $\eta^2_p = .13$), with Bonferroni-corrected pairwise comparisons revealing that the somatic condition ($M = 1439.30$Hz, $SE = 55.07$Hz) resulted in significantly higher spectral centroid compared to internal ($M = 1327.16$Hz, $SE = 24.91$Hz; $p = .045$), with no significant differences to external ($M = 1341.97$Hz, $SE = 34.69$Hz). This result implies a brighter tone quality in the somatic condition (Figure 5).

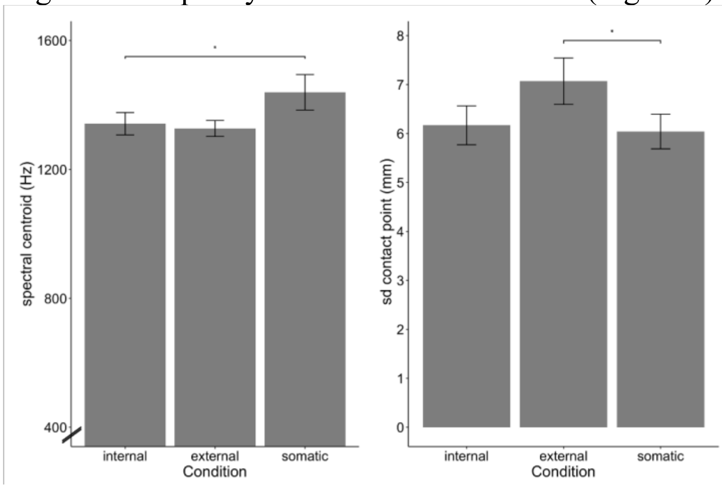

Figure 5 Left panel: Effects of Focus Condition on mean spectral centroid. Right panel: Effect of FOA on standard deviation of bow contact point. * denotes a statistically significant difference, $p < .05$. Error bars indicate standard error of the mean. Descriptive statistics broken down by expertise and focus condition are provided in the supplemental materials.

No main effects of Focus Condition were found for *SD* spectral centroid ($F(2,52) = 1.60$, $p = .212$, $\eta^2_p = .06$), mean RMS ($F(1.54,41.49) = 0.25$, $p = .720$, $\eta^2_p = .009$), *SD* RMS ($F(1.38,40.12) = 0.95$, $p = .366$, $\eta^2_p = .03$), mean roughness ($F(1.63,40.83) = 0.19$, $p = .782$, $\eta^2_p = .008$) or *SD* roughness ($F(1.43,35.85) = 0.44$, $p = .580$, $\eta^2_p = .02$). No significant interactions were found. However, significant Expertise effects were found for all MIR variables apart from mean spectral centroid (Table 4), indicating that experienced violinists played quieter and with less roughness than novices, and had higher consistency than novices in all acoustic features.

Table 4. Expertise results of mixed ANOVAs for spectral centroid, spectral flux, roughness, and fullness.

				Experienced	Novice
Measure	F value	P value	η^2_p	*M*(*SE*)	*M*(*SE*)
M spectral centroid	0.17(1,25)	.684	.007	1382.12(42.55)	1356.84(44.12)
SD spectral centroid	7.12(1,26)	**.013***	.22	111.81(13.94)	164.41(13.94)
M RMS	5.14(1,27)	**.032***	.16	0.08(0.01)	0.12(0.01)
SD RMS	6.57(1,29)	**.016***	.19	0.02(0.01)	0.04(0.004)
M Roughness	5.97(1,25)	**.022***	.44	0.04(0.01)	0.09(0.01)
SD Roughenss	7.02(1,25)	**.014***	.22	0.03(0.01)	0.08(0.02)

* denotes a statistically significant effect.

Motion capture

Bow contact point

For mean contact point there was no effect of Focus Condition ($F(2,56) = 1.29$, $p = .284$, $\eta^2_p = .04$), and no interaction effect. There was an effect of Expertise ($F(1,28) = 24.84$, $p < .001$, $\eta^2_p = .47$), such that experienced violinists ($M = 141.15$mm, $SE = 1.97$mm) had a contact point further from the bridge compared to novices ($M = 127.72$mm, $SE = 1.84$mm).

For *SD* contact point, there was a main effect of Focus Condition ($F(1.60, 48.12) = 4.98$, $p = .016$, $\eta^2_p = .14$), and no interaction effect. There was no effect of Expertise ($F(1,30) = 0.71$, $p = .406$, $\eta^2_p = .02$). For the effect of Focus Condition, pairwise comparisons showed a significant difference between external and somatic ($p = .042$), such that standard deviation of contact point was lower in somatic ($M = 6.042$mm, $SE = 0.35$mm) than external ($M = 7.07$mm, $SE = 0.48$mm). These results indicate that consistency of bow-string contact point improved in the somatic condition compared to the external condition. There were no significant differences compared to internal ($M = 6.17$mm, $SE = 0.40$mm, Figure 5).

Scroll sway

For scroll sway, there was no main effect of Focus Condition ($F(2, 54) = 1.33$, $p = .273$, $\eta^2_p = .05$), but there was a significant effect of Expertise ($F(1,27) = 11.04$, $p = .003$, $\eta^2_p = .29$), and an interaction effect ($F(2,54) = 3.93$, $p = .025$, $\eta^2_p = .13$). Experienced violinists ($M = 10.86$mm, $SE = 0.91$mm) displayed more scroll sway than novices ($M = 6.78$mm, $SE = 0.82$mm). Following up the significant interaction effect, simple effects analysis showed a significant effect of Focus Condition for novices ($F(2,30) = 6.33$, $p = .005$, $\eta^2_p = .30$), and no effect for experienced violinists ($F(2,24) = 1.70$, $p = .204$, $\eta^2_p = .12$). Pairwise comparisons for the novice group revealed significantly more scroll sway in the somatic condition ($M = 7.92$mm, $SE = 0.75$mm, $p = .003$) compared to internal ($M = 6.26$mm, $SE = 0.64$mm), while the difference between somatic and external ($M = 6.16$mm, $SE = 0.82$mm), was approaching statistical significance ($p = .050$, Figure 6).

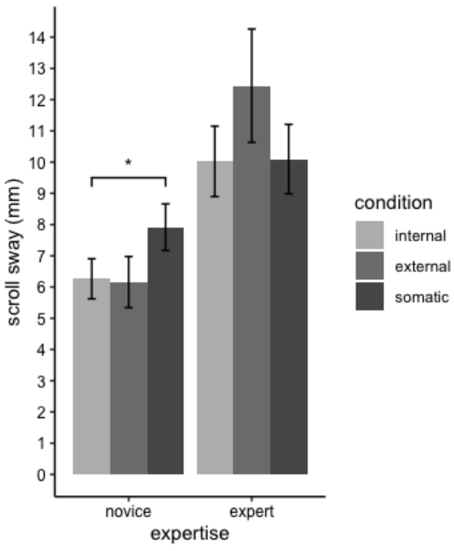

Figure 6. Significant effect of focus condition on scroll sway for novices. * denotes a statistically significant difference, $p < .05$. Error bars indicate standard error of the mean.

Bow acceleration

There was no main effect of Focus Condition on mean acceleration ($F(1.47,41.16) = 2.12$, $p = .144$, $\eta^2_p = .07$), and no further interaction or Expertise effects. For *SD* acceleration, there was no main effect of Focus Condition ($F(1.08,29.18) = 1.51$, $p = .231$, $\eta^2_p = .05$). There was a significant effect of Expertise ($F(1,27) = 6.24$, $p = .019$, $\eta^2_p = .19$), such that experienced violinists ($M = 712.54mm/s^2$, $SE = 67.35mm/s^2$) had more variable bow acceleration than novices ($M = 470.32mm/s^2$, $SE = 69.72mm/s^2$), and there was no further interaction effect.

EMG

A main effect of Focus Condition was found for the deltoid ($F(1.35,40.50) = 6.34$, $p = .010$, $\eta^2_p = .17$) and the tricep ($F(2,58) = 4.01$, $p = .023$, $\eta^2_p = .12$) muscles, with no Expertise effects or interactions (Figure 7). For the deltoid, a Bonferroni corrected pairwise comparisons showed significant difference between internal ($M = 36.46mV$, $SE = 4.33mV$) and somatic ($M = 33.16mV$, $SE = 3.89mV$, $p = .023$), while the difference between external ($M = 33.29mV$, $SE = 3.87mV$) and internal was approaching significance ($p = .056$). These results indicate that deltoid muscle activity was significantly reduced under somatic focus compared to internal. For the tricep, pairwise comparisons showed no significant differences after Bonferroni correction, although the highest muscle activity was again observed in the internal condition ($M = 5.20mV$, $SE = 0.45mV$), with somatic ($M = 4.86mV$, $SE = 0.42mV$) and external ($M = 4.85mV$, $SE = 0.42mV$) being descriptively very similar). This non-significant trend reflects a similar pattern to the deltoid muscle.

For the bicep muscle, there was no effect of Focus Condition ($F(2,60) = 0.33$, $p = .719$), no interaction effect, and no effect of Expertise ($F(1,30) = 3.84$, $p = .060$).

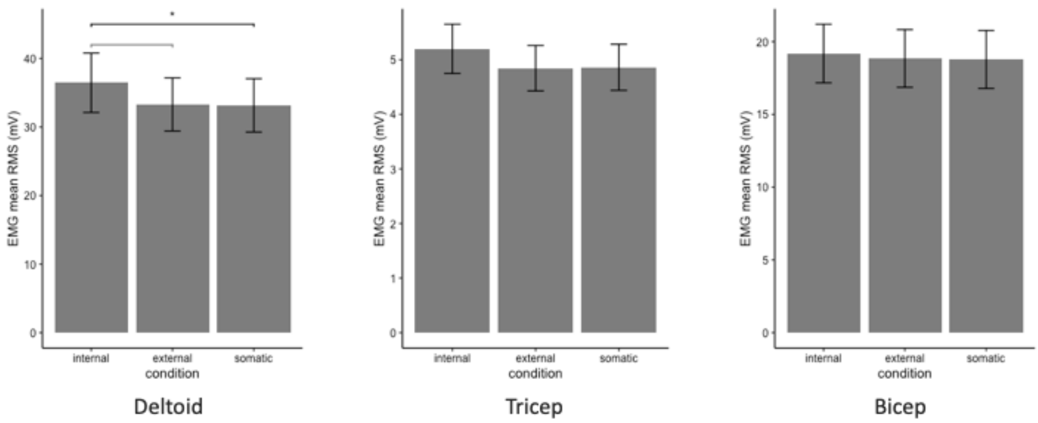

Figure 7. Focus Condition effects on EMG activity in deltoid, tricep, and bicep. * denotes a statistically significant difference, p < .05. Grey significance line denotes a difference approaching statistical significance. Error bars indicate standard error of the mean. Descriptive statistics broken down by expertise and focus condition are provided in the supplemental materials.

Relationships between variables

As a final step, we explored relationships between physiological and physical variables with audio, in an attempt to gain insight into the mechanisms of sound-production. To this end, we ran correlation tests comparing a) EMG activity of the three muscles and b) motion capture variables (bow velocity, acceleration, contact point, and scroll sway) with audio variables RMS, spectral centroid and roughness. Correlations were run on mean measurements only, not standard deviations. For these purposes, the motion data was segmented to match the audio signal processing so that only motion during the bowing sections was represented. As some variables were not normally distributed, we applied Spearman's correlations. For the EMG correlation block the alpha threshold for significance was adjusted to $p = .005$ (9 correlations) and for the motion capture block alpha was adjusted to $p = .004$ (12 correlations). We found no significant correlations between either EMG activity or motion features after alpha correction. This indicates that the audio measures were not directly related to either muscle activity or motion features.

Discussion

This study investigated effects of the psychological performance technique attentional focus on several stages of sound-producing action in both novice and experienced violinists, comparing effects of three attentional foci - internal (on arm movement), external (on sound), and somatic (on bow-string resistance, see Table 1). We found significant effects of focus of attention (FOA) on spectral centroid of violin sound, consistency of bow contact point, novices' violin scroll sway, and EMG activity of the deltoid and tricep muscles. These results suggest that a change in psychological approach can impact motor control of sound production at several stages of the action-sound chain (see Figure 1), including an aspect of global motor behaviour (novices scroll sway). On the other hand, we found no effects of FOA for acoustic features RMS (i.e., loudness) or roughness, bow acceleration, or bicep muscle activity. In partial support of our first hypothesis, we observed, on the whole, performance improvements under somatic focus compared to internal. However, we did not observe any performance benefits of the external focus relative to internal, suggesting that the somatic focus on bow-string resistance was more beneficial to performance than the external focus on sound. Our second hypothesis was partly supported, with Expertise significantly affecting several outcome variables (acoustic features, bow acceleration, bow contact point, and scroll sway). However, we found an interaction effect of Expertise and Focus Condition, for the outcome measure violin sway only, suggesting that FOA effects on all other outcome variables were largely independent from expertise.

Acoustical outcomes

We found a significant main effect of focus condition on the acoustic stage of sound production. Results showed that spectral centroid increased under a somatic focus on bow-string resistance, relative to an internal focus on arm movement. In contrast, we found no effects for RMS or roughness. As spectral centroid is widely agreed to be associated with perceived brightness of a sound (e.g. Trapasso, 2013), and violins with higher brightness have been judged as better quality by experts (Łukasik, 2005), we deemed a higher spectral centroid to indicate an improvement in tone quality. This finding thus partially supports our first hypothesis that performance outcomes would improve under somatic focus compared to internal. As the somatic focus constitutes a specific type of external focus, this is in line with the *Constrained Action Hypothesis*

(CAH), previous research in sport (e.g. Neumann, 2019; Wulf, 2013; Wulf & Lewthwaite, 2016) and music (Atkins, 2017; Duke et al., 2011; Mornell & Wulf, 2019). However, we unexpectedly found no evidence of performance benefits under the external focus on sound compared to the internal focus. This result does not support the CAH.

These results can be considered in terms of the distance effect that performance improves as FOA gets further from the body, which was supported by Duke, Cash, and Allen (2011) for a keyboard task, and Atkins (2017) for singing. Previous studies in music have defined a focus on sound as a more distant external focus relative to a focus on the musical instrument (Duke et al., 2011; Stambaugh, 2017), and following this rationale, the current study's external focus may be considered more distal than the somatic focus. Our findings then, would not support a distance effect, as the focus on sound did not improve performance compared to the focus on bow-string resistance. Indeed, more distal external foci may not always produce the best performance results. Singh and Wulf (2020) found that a proximal external technique-based focus was more beneficial than distal external for those lacking in expertise (Singh & Wulf, 2020). Similarly, the somatic focus may afford the benefit of drawing attention away from movement mechanisms (avoiding constrained action) while also bringing awareness to bow technique. However, while our findings do not support the distance effect, neither do they refute such an effect. For example, it is possible that participants experienced the sound of the violin as closer than the bow-string resistance. Further research could explore how performers experience the closeness of different foci in musical tasks.

Unlike Singh and Wulf (2020), our findings for tone brightness applied to both experienced violinists and novices, but this may be a reflection of the complex nature of violin tone production, which is characterised by the careful balancing of several bowing parameters (Edgerton et al., 2014), and control of several degrees of freedom of motion (Konczak et al., 2009). The complexity of this motor skill may imply that even for experienced players, bowing movements are not fully automatised, meaning that an optimal external focus should bring attention to the technical means of sound production, rather than the sound itself. Additionally, our results may have been different if we had a higher level of expertise in our sample. Another point to note about this finding is that spectral centroid in violin sound has been shown to be mainly influenced by bow force (Schoonderwaldt, 2009b), thus increased pressure of the bow into the string under the somatic focus may have underpinned this effect. Future studies should attempt to verify this by measuring changes in bow force due to attentional focus, which may be achieved through use of specially designed systems for tracking bowing parameters (Pardue et al., 2015).

In contrast, we found no effects of FOA on RMS (i.e., loudness) or roughness (i.e., sensory dissonance) of sound produced. These contrasting findings reflect the multifaceted nature of even a simple string instrument sound production task in that there is a myriad of sound features which may or may not be affected. That we observed effects of attentional focus for spectral centroid and not the other features, indicates that bowing mechanics may be altered in a way that changes one aspect of tone but not others. This is consistent with mathematical understandings of bowing mechanics as a dynamic and complex system (e.g. Edgerton et al., 2014). Further research should explore the bowing features which might control the roughness of violin sound. Overall, our results indicate that a somatic focus on bow-string resistance during violin playing can affect the acoustical output of the sound-producing action via an increase in the brightness of tone produced, but not through the RMS or roughness of the sound.

MIR feature selection is clearly an important process in the current paradigm, as the features chosen for analysis may define whether or not effects are observed. We based our feature selection on previous research, and aimed to select features that were reasonably well understood in terms of their perceptual attributes, but it is unlikely that FOA would affect all aspects of sound produced by a musician, and it is possible that other MIR features would have produced different results. As there is currently no standard acoustic measure to represent violin tone quality as a totality, it was a necessary limitation to focus on a select few features of tone. Further research exploring FOA in more expressive musical tasks with a fewer number of trials could utilise perceptual ratings. Nonetheless, the use of MIR features in the current study provides a reliable and quantifiable way of measuring changes in the mechanics of sound production, and is an important contribution to this field of research.

Physical outcomes

To assess effects of FOA on the physical stage of the sound-producing action, we examined technical bowing parameters of bow acceleration, bow contact point and violin sway. We found a main effect of focus condition on the consistency of bow contact point, such that bow contact point was less variable in the somatic condition relative to external. This finding indicates that a change in psychological approach may influence physical aspects of sound-producing motor control. In line with pedagogical perspectives, we considered the lower standard deviation of bow contact point observed in the somatic condition to indicate an improvement in bow control (Fischer, 1997). This result does not support our first hypothesis, as there were no differences relative to the internal focus, but rather points to a benefit of the somatic focus over the external focus. This is in line with our previous suggestion that the somatic focus encouraged awareness of bow technique, and strengthens our proposition that a focus on bow-string resistance might be more helpful to violinists' tone production than a focus on the sound itself. Indeed, this effect may be driven by increased attention to tactile feedback from the instrument, supporting Stambaugh's (2017; 2019) suggestion that awareness of tactile feedback is important for instrumental musicians and may be a contributing factor to FOA effects.

We found no effects of FOA on bow acceleration or mean bow contact point. A possible reason for the lack of any effect here may have been the very controlled nature of the task, which left little room for variation in bow acceleration. More variability in these parameters might have been observed in more complex, less controlled musical tasks, or with non-musician participants.

Results further demonstrated that attentional focus significantly affected novices' freedom of body motion, as measured by micro changes in violin scroll sway. Novices' instrument sway significantly increased under somatic focus compared to internal, while experts were unaffected. The systematic changes in sway observed here, were a matter of millimetres in magnitude, suggesting changes in micro-motion rather than large swaying motions which could be disruptive to playing technique. As freedom of body motion is considered a positive pedagogical outcome (Roos, 2001), inhibiting overall body motion has been shown to negatively impact music performance (Rozé et al., 2020; Turner & Kenny, 2011), and increases in micromotion while sitting have been associated with reductions in pain (Vergara & Page, 2002), we interpreted increased instrument sway as representing subtle relaxations of posture and thus an improvement in freedom of body motion. This finding therefore partially supports our first hypothesis, with freer motion in the somatic focus relative to internal focus.

Experienced violinists exhibited significantly more sway than novices overall, meaning that novices' sway behaviour became closer to that of experienced players under the somatic focus, and supporting the interpretation of this effect as a performance improvement. This result supports previous findings that constrained action under an internal focus can lead to global changes in motor behaviour – i.e., changes to movement that are not specific to the part of the body focused on for the task (Wulf & Dufek, 2009). Indeed, it is argued that somatic training methods encourage reductions in stiffness through attention to subtle body sensations (Mattes, 2016), and our finding that the somatic focus increased sway may reflect similar mechanisms. Further research could build on this finding by exploring how changes in instrumental sway behaviour may affect perceptions of performance, or how FOA might affect larger gestural behaviour in expressive music performance.

Physiological outcomes

Our first hypothesis was also partly supported for the physiological stage of the sound production task. In line with previous research that an external focus promotes more efficient muscle use (e.g. Marchant & Greig, 2017; Neumann & Brown, 2013; Vance, Wulf, Töllner, McNevin, & Mercer, 2004), we found significantly reduced muscle activity in the deltoid muscle (shoulder) under somatic focus (a type of external focus) compared to internal. This, to our knowledge, is novel evidence of this physiological effect in a music task. In somatic training methods, it is thought that attending to body sensations can reduce excess muscle tension, and it has further been suggested that this process is underpinned by the CAH (Mattes, 2016). Our findings tentatively support this, as the somatic focus, which aimed to bring awareness to tactile sensations (i.e., body sensations) through the violin bow caused decreased muscle activity in the right shoulder. Further research could explore how FOA affects muscle activity in specific muscles known to be problematic for certain instruments, and how this might be useful in preventing playing-related injuries.

However, we found no significant effects of FOA for the bicep muscle, and effects on the tricep muscle were not significant (employing Bonferroni correction). We suggest that the reason these muscles were not affected by attentional focus may have been because they followed an alternating activation pattern which allowed rest periods in which excess tension could dissipate. These rest periods may have negated any over-activation effects caused by the internal focus. Future research might further investigate how muscle activation patterns mediate increases in EMG activity as a result of constrained action.

Expertise effects

Our second hypothesis was that performance outcomes and effects of FOA would be different for experienced players and novices. This hypothesis was supported for several acoustic features, showing that, compared to novices, experienced violinists' sound was characterised as significantly less variable in spectral centroid, roughness and RMS, indicating greater control of sound consistency. Experienced players also played significantly quieter than novices and with less mean roughness, and their bow technique was characterised with higher variability of acceleration and a bow contact point further from the bridge. Also, experienced players' violin sway was greater than novices, indicating greater freedom of overall body motion. This distinct characterisation of experienced and novice players, even for a very simple task, is in line with evidence that violin bowing is a highly complex motor skill which may take years to master (Konczak et al., 2009). These findings can inform future studies that require parameters with which to measure quality of violin playing or to define violin expertise. In particular, lower mean roughness, lower standard deviation of MIR features, and higher violin sway may be useful features for characterising experienced players.

Our hypothesis that effects of FOA would be mediated by expertise was supported only for the violin sway measure. On all other measures no interaction of expertise and condition was observed. First, we suggest that the interaction effect of expertise and condition for instrument sway might indicate that the experienced violinists had learned to integrate sway behaviour with their playing in such a way that it would be unaffected by constrained action. Experienced players were likely very comfortable with the violin posture and found the bowing task relatively easy, meaning that even under an internal focus, their overall body motion remained free. On the other hand, novices were unfamiliar with the playing posture and may have therefore been more susceptible to constrained action effects on their swaying behaviour. Secondly, the lack of interaction effects in other measures supports previous findings in sport that the CAH may affect motor performance regardless of expertise (Wulf, 2013). However, as discussed earlier, our findings generally point to performance benefits under a somatic focus on bow-string resistance for both novices and experts rather than an external focus on sound, and we believe that this is due to the complex nature of the sound production task, which requires attention to technical means of sound production rather than to the end goal of sound itself. So, the lack of expertise effects observed here may be due to the complex nature of violin tone production, and indeed, a sample of violinists with a wider range of expertise (i.e., elite solo performers) may yield different results. A final point to note on expertise is that it has been shown that training in certain musical skills, such as focussing on various instruments in an orchestra simultaneously, affects attentional capacities (Wöllner & Halpern, 2016). In this study, conductors had better divided attention skills compared to pianists, while more experienced musicians outperformed less experienced ones. In the current sample it is unknown if the experienced violinist group had better attentional capacities than the other group, and therefore might have been better at following the focus instructions. Future research using this paradigm could take individual differences in attentional capacity into consideration.

Relationships between variables

As a final exploratory measure, we investigated the relationships between physiological muscle activity and motion variables with MIR features. We observed no significant correlations between motion or EMG measures and audio features, showing that the measures taken at different stages of the sound-producing action chain represent distinct aspects of the action. Although it may seem surprising that bow motion features did not correlate with MIR outcomes, these relationships may require measurement of other variables such as bow force, and flatness of bow hair, in order to understand them fully. While previous research has suggested that bow contact point is related to loudness (i.e., RMS, Edgerton et al., 2014), the lack of this relationship here might be explained by a lack of variation in these parameters due to the strict nature of the task. Gaining a full picture of how motion and physiological parameters contribute to violin sound production would be a useful topic for further research.

Limitations

Several limitations of the current study should be considered. Firstly, the task used was a reductive technical exercise not representative of the full scope of what music performance encompasses. Nonetheless, the exercise was a realistic one, important to the early stages of learning to play the violin, and has provided key findings which can inform further study of more expressive, complex musical tasks. It should also be noted that the current study examined only *performance* effects of FOA, not *learning* effects. Exploring FOA effects on the learning of violin bowing skills would be a suitable topic for further research. Furthermore, the novices used in the current study had only a short training session, and it is possible that providing a longer time to establish bow technique for novices would show different results. Finally, the current study took place in a laboratory, where participants were required to wear various body sensors, which is undoubtedly an unusual music performing environment, and results may differ in a more naturalistic setting. Future research could thus build on the current findings by aiming to replicate them outside of the laboratory, with more complex, expressive musical tasks.

Conclusions

This study provides novel evidence that the psychological performance approach of attentional focus can affect physiological, physical and acoustical aspects of motor control during a violin sound production task, in both experts and novices. Results also showed that attentional focus affected a more global aspect of motor control, namely freedom of body motion measured through instrument sway, for novices but not experts. Our findings provide support for the constrained action hypothesis in violin sound production (a continuous instrumental sound production task), in line with previous FOA research in sport. Under the assumption that a focus on sound can be considered more distant from the body than a focus on bow-string resistance, our results indicate no evidence for the distance effect (that more distal foci produce better performance), although further research is needed with more clearly evidenced definitions of what constitutes a distant focus in a musical task. Nevertheless, our findings indicate that the complex motor skills of violin tone production benefit from a somatic focus on bow-string resistance which allows attention to the technical means of sound production (Singh & Wulf, 2020), compared to an internal focus on movement mechanisms. Furthermore, the performance benefits we found of the somatic focus, may support putative mechanisms of somatic training methods for improving performance by encouraging awareness of body sensations and movement habits (Mattes, 2016). We additionally found that attentional effects were modulated by expertise only for the freedom of body motion measure, indicating that aspects of attentional focus effects on sound production may occur regardless of violin playing expertise. Future research on this topic should investigate effects of attentional focus on expressive musical outcomes, and in situations of psychological pressure, as well as possible connections of attentional focus effects on muscle activity with playing related injuries.

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Study 2.

Effects of attentional focus on motor performance and physiology in a slow-motion violin bow-control task: Evidence for the constrained action hypothesis.

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Effects of Attentional Focus on Motor Performance and Physiology in a Slow-Motion Violin Bow-Control Task: Evidence for the Constrained Action Hypothesis in Bowed String Technique

Emma Allingham[1] and Clemens Wöllner[1]

Abstract

The constrained action hypothesis states that focusing attention on action outcomes rather than body movement improves motor performance. Dexterity of motor control is key to successful music performance, making this a highly relevant topic to music education. We investigated effects of focus of attention (FOA) on motor skill performance and EMG muscle activity in a violin bowing task among experienced and novice upper strings players. Following a pedagogically informed exercise, participants attempted to produce single oscillations of the string at a time under three FOA: internal (on arm movement), external (on sound produced), and somatic (on string resistance). Experienced players' number of bow slips was significantly reduced under somatic focus relative to internal, although number of successful oscillations was not affected. Triceps electromyographic activity was also significantly lower in somatic compared to internal foci for both expertise groups, consistent with physiological understandings of FOA effects. Participants' reported thoughts during the experiment provided insight into whether aspects of constrained action may be evident in performers' conscious thinking. These results provide novel support for the constrained action hypothesis in violin bow control, suggesting a somatic FOA as a promising performance-enhancing strategy for bowed string technique.

Keywords

focus of attention, violin performance, motor skill performance, expertise, electromyography

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Virtuoso music performance exemplifies some of the most impressive feats of motor control of which humans are capable. Musicians spend a huge proportion of their lifetime acquiring these skills (Watson, 2006), and it is the job of music educators to nurture effective skill acquisition and performance habits in their students. Research on motor performance has evidenced that the object of a performer's focus of attention (FOA) can significantly affect motor skill learning and performance (Wulf, 2013), but despite the relevance of this effect to music education, only a handful of studies have applied this paradigm to music education contexts. Exploring effects of FOA in musical motor tasks is relevant to the field because it investigates the tangible effects that small changes in a music instructor's words may have on a performing student. Furthermore, this area of research highlights the need for music educators to equip students with not only technical playing skills but also performance psychology skills (Connolly & Williamon, 2004). Thus, potential benefits of FOA to preparation for and execution of music performance deserve further empirical investigation. In the current study, we aimed to test effects of FOA on motor performance in a violin bow-control task.

Related Literature

Focus of Attention Research

Many instrumental music teachers may have experienced the phenomenon of *paralysis by analysis* (Ehrlenspiel, 2001), in which thinking consciously about how a motor skill is executed causes difficulties in action execution. For example, when teachers are asked to explain the mechanics of a particular skill, they may find themselves temporarily unable to perform the skill to their usual standards. This effect has been demonstrated in a wealth of motor control studies, mainly in the context of sports, which have shown that motor performance improves when individuals adopt a focus on the environmental effect or goal of their action (i.e., an external focus) compared to a focus on the movement mechanisms of the action (i.e., an internal focus; for a review see Wulf, 2013). With a tennis serve, this could be the difference between thinking about where the ball should bounce (external focus) or thinking about how the arm should swing the racquet (internal focus). With a violin bow stroke, this could be the difference between thinking about the sound produced (external focus) versus thinking about the arm motion (internal focus).

Some studies have challenged the generalizability of these FOA effects. For example, effects may depend on the attentional load of tasks (Sherwood et al., 2020) or may not hold true for novices (Castaneda & Gray, 2007; Perkins-Ceccato et al. 2003). However, the majority of the research literature on this topic shows support for the beneficial effects of an external focus compared to internal focus, particularly when focus conditions are well controlled and definitions of internal and external foci are consistent with previous studies (Singh & Wulf, 2020; Wulf, 2013).

In the FOA paradigm, attentional foci are induced via verbal instructions, and in some cases, differing effects on performance have been shown between instructions varying in only one or two words (Wulf, 2013). In music teaching, instructions and explanations are often given through verbal communication (Schippers, 2006); therefore, the pedagogical value of FOA research in music lies in exploring the psychological and physiological impact that small changes in verbal communication can have on performers' ability to play well.

In addition to motor performance, this effect has been shown in motor learning processes such that an external focus may improve skill retention and transfer (Becker & Fairbrother, 2019; Song, 2019). Adopting an external FOA also forms a key part of the *optimizing performance through intrinsic motivation and attention for learning* theory of motor learning (Wulf & Lewthwaite, 2016), which also includes methods of enhancing the student's expectancies for future performances and promoting learner autonomy. Furthermore, motor performance research has found that an internal focus may cause a physiological change in the motor system through increased electromyographic (EMG) muscle activation, indicating decreased efficiency of muscle use (Marchant & Greig, 2017; Neumann, 2019; Neumann & Brown, 2013; Vance et al., 2004). Such an effect in musicians may have implications for efficient use of the body in performance, which could be important in the prevention of overuse injuries.

Theoretical Underpinnings

The *constrained action hypothesis* (CAH; McNevin et al., 2003; Wulf et al., 2001) provides a theoretical explanation for the FOA effect. CAH posits that focusing on movement mechanisms evokes self-consciousness in the performer and triggers attempts to control automatized motor processes, resulting in performance impairment. In support of this, a recent study has provided neurological evidence that an internal focus promotes conscious motor processing in the form of increased coherence between verbal, analytical, and motor planning brain regions (Law & Wong, 2020). This theory is also closely connected to issues of performance under pressure. For example, the phenomenon of "choking under pressure" is theorized to occur when a performer tries to consciously apply declarative motor knowledge to an action that had become automatized at an implicit level (Beilock & Carr, 2001; Masters & Maxwell, 2008). Awareness and understanding of CAH can greatly benefit music educators in making informed decisions about how use of language in a music lesson may impact a student's motor control system and when considering how to best support students in coping with performing under pressure.

CAH also reflects understandings of optimal performance in music. For example, Kenny (2011) suggested that music performance anxiety could be avoided by shifting focus away from the self, whereas loss of self-consciousness and task absorption are indicators of flow states, a marker of optimal performance (Csikszentmihalyi, 1990). CAH is also relevant to pedagogical approaches when applied to the learning process. For example, the CAH seems to encourage implicit learning approaches (e.g., Poolton & Zachry, 2007), in which the student learns motor skills without explicit instructions, or discovery learning techniques are employed (Bakker, 2018; Fowler, 1966; Raab et al., 2009), where the student is encouraged to problem-solve for themselves. An external FOA could be a useful teaching tool in these approaches because attention is placed on the task outcome rather than the process and direct movement instructions are not given.

Attentional Focus in Music

FOA effects in music performance is an emerging field. In a seminal study, Duke et al. (2011) found that an external FOA on sound improved temporal evenness in skill transfer of a keyboard playing task relative to internal foci on fingers, piano keys, and piano hammers in a sample of 12 nonpianists, although no effect was observed in the four experienced pianist participants. Similarly, Atkins (2017) showed that expert ratings of experienced singers' performances were improved under an external focus on filling the room with their sound compared to other foci directing their voice to different objects in the room or focusing on their soft palate or vibrato. A study on the expressive performances of a group of various experienced instrumentalists found that an external focus on playing for the audience and the expressive sound of the music produced higher expert performance ratings compared to an internal focus on movement technique and note accuracy (Mornell & Wulf, 2019). These studies offer support for the CAH in musical contexts and suggest the suitability of inducing external FOA as a music pedagogical tool for improving performance.

However, other studies have yielded less clear results. For example, a study on FOA in untrained singers found improvements in expert ratings of performance quality when focusing externally on a point on the wall and on a microphone but also found improvements when adopting an internal focus on feeling the vibrations in the zygomatic arch of their cheekbones (Atkins & Duke, 2013). The authors noted that tactile sensory feedback may have influenced motor behavior in this condition. In addition, Stambaugh (2017) found no significant effects of FOA on skill retention and transfer in a MIDI wind-controller task in a sample of both novice and experienced woodwind players and no effect of FOA on the performances of middle school brass and woodwind players (Stambaugh, 2019).

Current music research on FOA also provides little consensus on the influence of expertise on FOA in music. In sports motor-performance contexts, it has been asserted that the benefits of an external over an internal focus hold true for both experts and beginners (Wulf, 2013), although recently, Singh and Wulf (2020) found that beginners may benefit more from a *proximal* external focus (i.e., closer to the body), which allows them to concentrate on movement technique. This is in opposition to the previously established *distance effect* (Singh & Wulf, 2020), that FOA further from the body are more beneficial (e.g., McNevin et al., 2003). In a music context, the role of expertise in FOA effects requires more attention so that educators may be advised as to how optimal foci may be likely to vary among different levels and abilities.

Researchers have also shown that an internal focus in the context of instrumental music-making might provide beneficial attention to tactile feedback (Stambaugh, 2019), for example, feeling vibrations or tension changes in the instrument. Certainly, the presence of tactile feedback has been shown to be important in consistency of expressive piano performance (Wöllner & Williamon, 2007), but how attention to tactile feedback affects music performance remains largely unstudied. In sports research, it has been theorized that elite athletic performers are likely to cultivate attention to bodily sensations (i.e., tactile and proprioceptive feedback) to maintain spontaneity, skill improvement, and injury avoidance (Shusterman, 2009; Toner et al., 2015; Toner & Moran, 2015). There also exists a parallel to this idea in music education, where somatic training methods such as the Alexander Technique (Cotik, 2019) or Feldenkrais method (Lee, 2018) encourage an awareness of body sensations as a way of learning more efficient use of the body. Indeed, it has been shown that somatic training methods may unwittingly capitalize on external FOA by encouraging attention to movement quality rather than movement mechanics (Mattes, 2016). Furthermore, attention to tactile feedback may have a particular relevance to learning a musical instrument (Stambaugh, 2019). Attention to tactile feedback through the instrument might, for example, play a role in developing a feeling for the instrument as an extension of the performer's body (Nijs, 2017). From a pedagogical perspective, deepening understandings of how attention to tactile feedback affects the motor system can inform instrumental teaching approaches. Thus, it is useful to investigate how a focus on tactile sensory feedback (i.e., a proximal external focus) through a musical instrument would compare with more standard internal and external foci.

FOA in Violin Bow Control

A fundamental tenet of string pedagogy is cultivating the ability to produce a beautiful sound quality (Galamian, 1962), a skill that can take years to master (Konczak et al., 2009). Central to this tone production skill is learning to balance bow speed, pressure, and contact point (i.e., position on the string) to produce the high amplitude harmonics (i.e., resonant frequencies of the fundamental tone) characteristic of good quality string sound (Collins, 2009). Producing this type of resonant string vibration has been described in terms of the physical string motion, in which the string first sticks to the bow and is pulled to one side, before slipping back to its original position (i.e., Helmholtz motion; Schoonderwaldt, 2009). The renowned pedagogue Simon Fischer created a useful slow-motion bowing exercise for developing a feeling for this stick-slip pattern and thus cultivating tactile sensitivity to the amount of downward bow force required for strong tone production (Fischer, 1997). The exercise involves a slow-motion version of the slip-stick pattern in which the student attempts to create single oscillations of the string at a time (see "The Current Study" section for more detailed description). This bowing exercise is a valuable pedagogical strategy because it distills the motor-control skills needed for good tone production into a slow, thoughtful task with clear performance feedback. Thus, the question of how FOA might impact bow-control ability during this slow-motion bowing task is highly relevant to pedagogical approaches of teaching tone production.

In a previous study in a violin tone-production task, we found that an FOA on tactile feedback increased tone brightness, reduced shoulder muscle activity, and increased novices' violin sway relative to an arm movement focus while improving consistency of bow-bridge distance relative to a sound focus (Allingham et al., 2021, in review). These results suggest benefits of a focus on tactile feedback in violin open-string tone production. With the current study, we aim to extend these findings to the highly nuanced bow-control skills of this slow-motion bowing exercise.

The Current Study

We investigated effects of attentional focus instructions on motor-skill performance in a violin-bowing task in both expert upper strings instrumentalists and bowed string instrument novices. We used a pedagogical slow-motion bow exercise, which aims to train nuanced bow-control skills necessary for producing good violin tone (see the following for the task description). The exercise requires a "less is more" approach, allowing the string to "do the work for itself," making it particularly suitable for exploring constrained action. Finally, the task enabled us to test CAH in the novel context of a very slow movement with an unfamiliar exercise to both experienced and novice players. As well as the standard internal and distal external foci, we included a novel focus intended to bring awareness to tactile feedback through the bow. We termed this a *somatic focus* because our aim was to mimic the kind of external FOA prompted by somatic training methods. This focus is, by Wulf's (2013) definition, an external focus because it does not refer directly to body movement; however, it is also intended to bring attention to sensations at the border of the internal-external dichotomy (Stambaugh, 2017) and thus may be viewed as being in between internal and external. Such a focus on tactile sensations may be positioned as either an internal or external focus depending on the instructions given, and in the current study, because the instructions refer to the instrument rather than the performer's body, the focus on tactile feedback constitutes an external focus. In addition to measuring FOA effects on task performance (see the following for details), we also explored physiological effects by measuring muscle activity in the bowing arm. This was informed by findings in sport that an internal FOA promotes inefficiency of muscle use (e.g., Neumann, 2019; Vance et al., 2004).

We hypothesized that the two external foci (on sound and on bow-string resistance) would result in fewer errors and more successful sounds in the bow-control task as well as reduced muscle activity (i.e., indicative of increased motor efficiency) compared to the internal focus (on arm movement). We also investigated whether experienced and complete novice string players would respond differently to FOA. Additionally, we aimed to explore how constrained action effects might be reflected in performers' conscious thoughts via an exploratory text-based analysis of participants' reported thoughts during the bowing task.

Method

Participants

We recruited 33 participants, 18 female and 15 male, between the ages of 19 and 42 (M = 24.97 years, SD = 4.80), all of whom were right-handed, via mailing lists and online advertising. We aimed to have a group of experienced violin/viola players (at least 10 years of training) and a group of novices (no experience playing a string instrument). We chose to recruit novice string players with training in another musical instrument to control for overall musical expertise and to ensure the training process was not too difficult for novice participants. We included viola players in the experienced group because the motor skills required for bowing on violin and viola are very similar. All participants performed the experimental task on a violin. We later excluded one participant from analysis when it became clear that this participant's level of violin training was notably lower than the experienced group but too high to qualify for the novice group. This resulted in a sample of 32 participants, 18 female and 14 male, between the ages of 19 and 42 (M = 24.94 years, SD = 4.87), all of whom played a musical instrument. The novice group had 16 participants between the ages of 21 and 37 (M = 24.56 years, SD = 3.88) who had studied an instrument that was not violin or viola for 2 to 21 years (M = 11.84 years played, SD = 4.66). The experienced group had 16 participants between the ages of 19 and 42 (M = 25.31 years, SD = 5.80) who had studied violin or viola for 10 to 36 years (M = 18.56 years played, SD = 6.12).

Equipment and Experimental Setup

We carried out the experiment in a 5 m × 5 m laboratory. All participants used the same violin, which was a Fastoso intermediate student model, mounted with an AKG Harman C411PP contact microphone. The microphone recorded sound through Audio Desk software and a MOTU 828MK3 audio interface. A green sticker was placed on the stick of the bow to mark the starting point for the bowing task. Trigno Delsys wireless surface EMG sensors were placed on the participant's bicep, triceps, and deltoid (i.e., shoulder) of the right arm. EMG data were recorded through Qualisys software and synchronized with audio via SMPTE timecode.

Procedure

Participants provided written informed consent before taking part in the study in accordance with the Local Ethics Committee guidelines. They answered a short demographic questionnaire and several questions about their musical training history. Next, EMG sensors were fitted in line with Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles guidelines (see www.seniam.org), and the signal to noise ratio was visually inspected to ensure correct placement. Because the current data collection took place alongside another study in which motion-capture data were collected, participants were also outfitted with Qualisys motion-capture jackets and reflective markers. Although the details of the motion-capture collection are not relevant to the current study, we wish to point out that this extra equipment was present during data collection. The motion-capture equipment was flexible, lightweight, and designed to allow a wide range of motion; therefore, it did not restrict movement or impede performance in the current study. The experimenter took care to ensure that the jackets did not disturb the EMG sensors through careful checking of sensor placement and inspecting the EMG signal. The first author (an experienced violin teacher) then carried out a short training session, teaching participants the bowing task and explaining the experimental procedure. For novices, the training lasted about 15 to 20 minutes and included learning the basics of holding the violin and bow. For experienced violinists, the training lasted about 5 to 10 minutes. During the training, the first author established that participants were able to cope with the basic technique, able to generate the desired *click* sound, and able to recognize a correct click compared to an error (i.e., a *bow slip*; see the following for details). Because Wulf (2013) pointed out that visual gaze should be controlled across focus conditions to avoid confounds, participants were instructed to keep their gaze on the violin A string during the task and not to look around the room while performing.

We carried out the experimental procedure alongside a second study comprising the same participants and the same focus instructions but different bowing tasks and separate analyses (Allingham et al., 2021, in review). We devised the two studies a priori to be analyzed separately, with different research questions and different dependent variables but one long, single data-collection session per participant. For each focus condition, participants carried out Bowing Task 1 (not analyzed in the current article), followed by Bowing Task 2 (detailed in the following). Task 1 comprised a simple open string bowing exercise and thus also provided a warm-up for the second task. In between each condition, participants were asked to verbally report what they had been thinking about during the tasks, and these comments were recorded on audio and transcribed by the researcher. Participants then sat quietly for 1 minute before the next condition to minimize carryover effects.

The bowing task is taken from Simon Fischer's (1997) book *Basics: 300 Exercises and Practice Routines for the Violin.* The exercise is a slow-motion sound production task where the student attempts to create single oscillations of the string at a time, each of which result in a small click sound. This click is the result of pulling the string to its maximum stretching point, releasing, and catching it again before it can continue to vibrate. If the performer pulls too hard, the bow will slip, creating a scratchy sound, and if they don't pull hard enough, they will produce no sound. As the bow travels, the performer encounters different parts of the bow, each with varying tension levels in the hair, and so the precise amount of downward bow force and lateral pull required to produce an oscillation varies with each attempt. Thus, the task requires very nuanced, slow motor-control skills, which underpin the fundamentals of quality sound production in string playing. The task allowed us to have a clearly quantifiable performance success metric (number of clicks and number of errors) while still being an ecologically valid bow-control task with direct relevance to the teaching of sound-production skills.

For each trial, participants were given 30 seconds to carry out the task, with the goal of making as many clicks and as few mistakes as possible. The exercise was carried out in a down bow direction, starting near the heel, and participants were instructed not to lift the bow off the string or change direction. They performed three trials for each focus condition. Participants were told they would be given instructions on what to think about during the task, and the focus instructions were then given verbally and reinforced for every trial. The focus instructions were:

Internal: Focus your attention on the movement in your right arm.
External: Focus your attention on the sound you produce.
Somatic: Focus your attention on the resistance of the bow against the string.

Data Analysis

Manipulation check. The reported thoughts given after each focus condition were analyzed to establish how well participants were able to follow the focus instructions. The first author coded each comment as either evidencing that the instruction was followed or not. Overall, 93% of all comments were judged as having followed the focus instructions, and no single participant was judged as unable to follow the instruction in all three conditions, indicating a high success rate.

Audio. The first author manually scored each audio recording by counting the number of correct clicks and errors (i.e., bow slips) using both audio and visual inspection of the sound wave and averaged scores across trials.

Electromyography. The EMG sensors contained an initial band-pass filter of 20Hz to 450Hz. All further processing was carried out using custom software in MATLAB. Data were first visually inspected, and one bicep muscle trial was excluded from the analysis due to movement artifacts. This exclusion comprised 0.005% of total EMG data points. Data were then mean centered and full-wave rectified, and a moving root mean squared (RMS) filter was applied (50-ms window length, 25-ms overlap) to give a measure of the power of the signal. This RMS curve was then maximum–minimum normalized to control for individual differences, and the mean RMS value (millivolts [mV]) was derived to indicate the average power of muscle activity during each trial. These values were averaged across trials.

Reported thoughts while performing. We carried out an exploratory text-based analysis of participants' reported thoughts during the experiment (using the same data used for the manipulation check), with the aim of exploring whether indications of constrained action effects might be evident in participants' recollected conscious thoughts. The data consisted of one comment per focus condition, in which the participants described what they had been thinking about (96 comments in total). To summarize the comments, five themes were derived from the data by the first author with a view to constrained action theory and somatic pedagogy. First, the theme of *curiosity* (displaying curiosity, interest in the process and exploring technical issues) aimed to capture evidence that participants were absorbed in the task itself rather than feeling self-conscious, in line with the notion that constrained action arises from a self-invoking trigger (Wulf & Lewthwaite, 2010). In opposition, the theme *trying hard* (feeling anxious about one's own performance or aiming for perfection) aimed to capture preoccupation with the self or self-performance. The *letting go* theme (relaxing, not caring about mistakes) aimed to indicate instances where participants felt relaxed and unconcerned about their performance, which would indicate absence of the conscious control brought about by constrained action (Wulf et al., 2001). The theme *noticing sensations* was conceived in line with somatic training pedagogy, aiming to indicate moments of nonjudgmental somatic awareness (Lee, 2018), and the theme of *physical discomfort* captured the experience of more negative body sensations. Thus, the presence of the trying hard theme might indicate constrained action effects, whereas curiosity, letting go, and noticing sensations themes may indicate the absence of such an effect. The physical discomfort theme may or may not relate to constrained action effects but nonetheless captured a relevant aspect of the data.

Comments were then randomized so that the focus condition/participant to which each comment belonged was obscured. The first author and a second coder then coded each comment with a 0 (theme not present) or 1 (theme present) for each theme in nonexclusive categories. This process was implemented to develop a single variable, reducing coder bias. Because Cohen's κ between the first two coders yielded an inter-rater agreement, $\kappa > .5$ ($M = .55$), for all themes, indicating reasonable agreement, a third independent coder was brought in to resolve disputes and produce final dichotomous variables with 100% agreement. Therefore, where there was disagreement, the majority decision of the three coders was taken.

Statistical analyses. Statistical analyses were carried out in R Project for Statistical Computing Software, Version 4.0.2 (www.r-project.org). All variables were screened for outliers such that values greater or less than 3 *SD* from the mean were excluded on a case-wise basis. This resulted in the removal of two outliers from the errors variable, one from clicks and one from the deltoid EMG variable. For the five quantitative dependent variables (number of clicks, number of errors, and EMG activity of bicep, triceps, and deltoid), we carried out individual mixed analyses of variance with focus condition (3) as the repeated measures factor and expertise (2) as the between-groups factor. Where Mauchley's test of sphericity was significant, we report the Greenhouse-Geisser corrected degrees of freedom. We report Bonferroni-corrected post hoc pairwise comparisons for any statistically significant main effects, and for any statistically significant interactions, we report simple effects analysis, also with Bonferroni-corrected *p* values.

Results

Audio

We analyzed outcome variables number of errors and number of successful clicks to investigate effects on task performance. For number of errors, there was no main effect of focus condition, $F(2, 56) = 2.37$, $p = .102$, $\eta_p^2 = .08$ (see Figure 1a), and no effect of expertise, $F(1, 28) = 0.77$, $p = .387$, $\eta_p^2 = .03$; but there was a significant

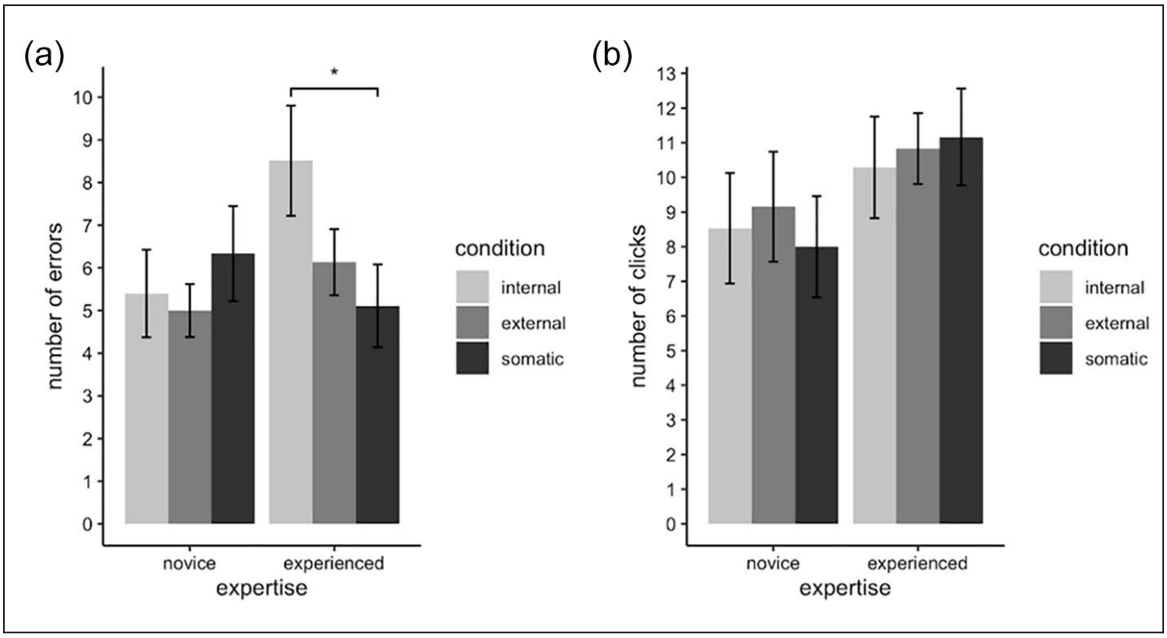

Figure 1. Audio results.
Note. Bar graphs depicting (a) mean number of errors and (b) mean number of clicks for each focus condition within each expertise groups. Error bars indicate the standard error of the mean.
$^*p < .05$.

interaction effect, $F(2, 56) = 4.83$, $p = .012$, $\eta_p^2 = .15$. A simple effects analysis revealed a statistically significant effect of focus condition for experts, $F(2, 28) = 6.36$, $p = .01$, $\eta_p^2 = .31$, but no significant effect for novices, $F(2, 28) = 0.94$, $p = .80$, $\eta_p^2 = .06$. Pairwise comparisons for the expert group revealed significantly higher number of errors in internal ($M = 8.51$, $SD = 5.00$) compared to somatic ($M = 5.11$, $SD = 3.76$, $p = .016$), with no significant differences compared to external ($M = 6.13$, $SD = 3.00$). This result indicates that experts made significantly more errors when focusing on arm movement compared to focusing on string resistance.

For number of clicks, there was no main effect of condition, $F(2, 58) = 0.21$, $p = .81$, $\eta_p^2 = .007$; no effect of expertise, $F(1, 29) = 1.65$, $p = .21$, $\eta_p^2 = .05$; and no interaction effect, (see Figure 1b). There was no evidence in either variable that expertise had a main influence on task performance.

Electromyography

We analyzed EMG muscle activity to determine physiological effects of attentional focus. For the triceps muscle, there was a main effect of focus condition, $F(2, 60) = 3.82$, $p = .028$, $\eta_p^2 = .11$ (see Figure 2a), such that the internal focus produced significantly higher muscle activity ($M = 5.12$ mV, $SD = 2.81$) compared to somatic ($M = 4.80$ mV, $SD = 2.60$; $p = .043$), with no significant difference to external ($M = 5.03$ mV, $SD = 2.92$). There was no effect of expertise, $F(1, 30) = 0.04$, $p = .85$, $\eta_\mathrm{p}^2 = .001$, and no interaction effect.

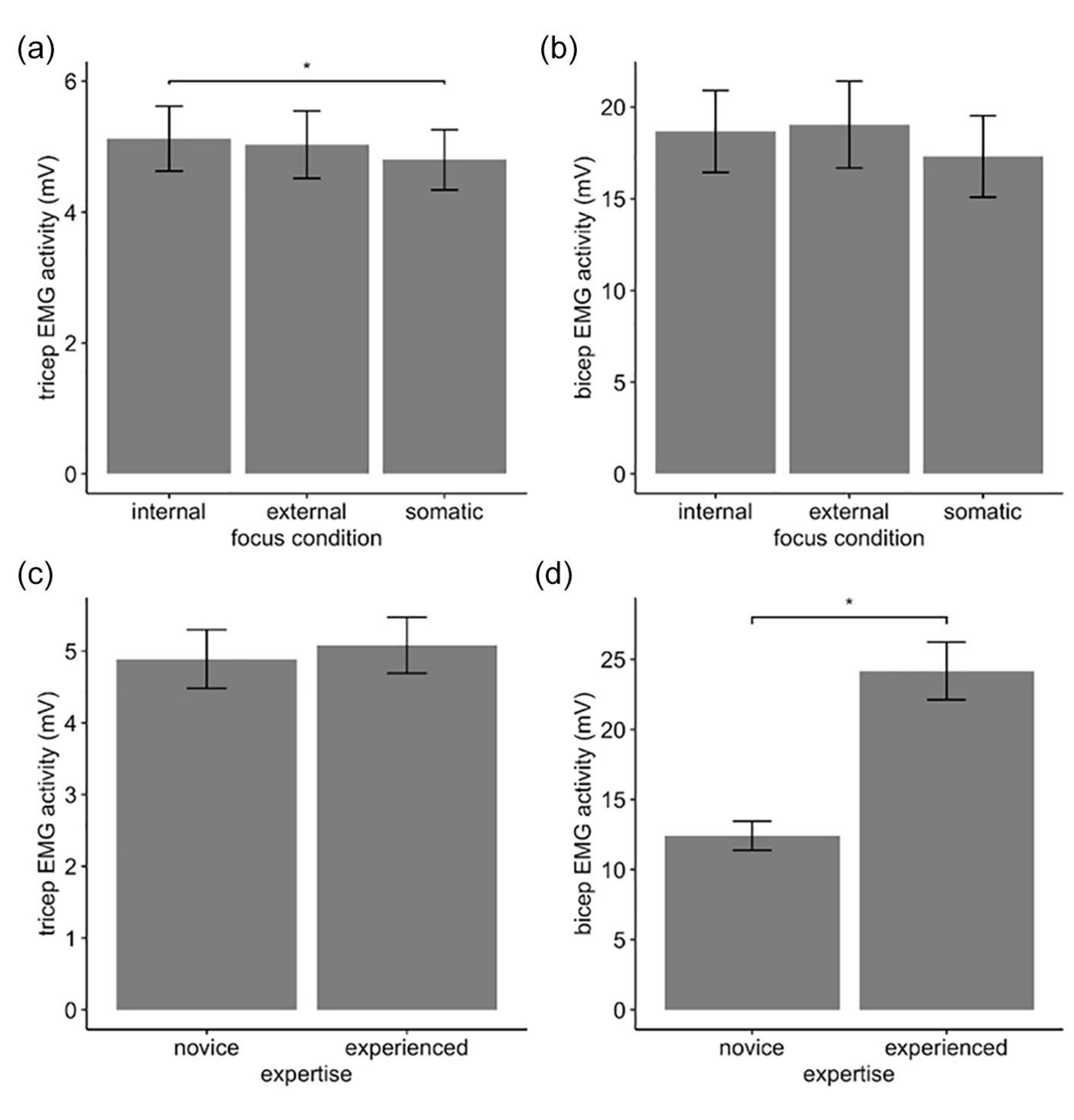

Figure 2. Electromyographic results.
Note. (a) Significant main effect of focus condition on triceps muscle, (b) nonsignificant effect of focus condition on bicep muscle, (c) nonsignificant effect of expertise on triceps, and (d) significant main effect of expertise on bicep muscle activity. Error bars indicate standard error of the means.
*p < .05.

For the bicep, there was no main effect of focus condition, $F(1.54, 44.8) = 3.09$, $p = .07$, $\eta_p^2 = .10$, but there was a main effect of expertise, $F(1, 29) = 8.78$, $p = .006$, $\eta_p^2 = .23$ (see Figure 2b), such that novices had significantly lower muscle activity (M = 12.42 mV, SD = 7.11) than experienced players (M = 24.17 mv, SD = 14.26). There was no interaction effect.

For the deltoid muscle, there was no significant effect of focus condition, $F(2, 58) = 1.78$, $p = .18$, $\eta_p^2 = .06$, or expertise, $F(1, 29) = 0.16$, $p = .69$, $\eta_p^2 = .006$, and no interaction effect.

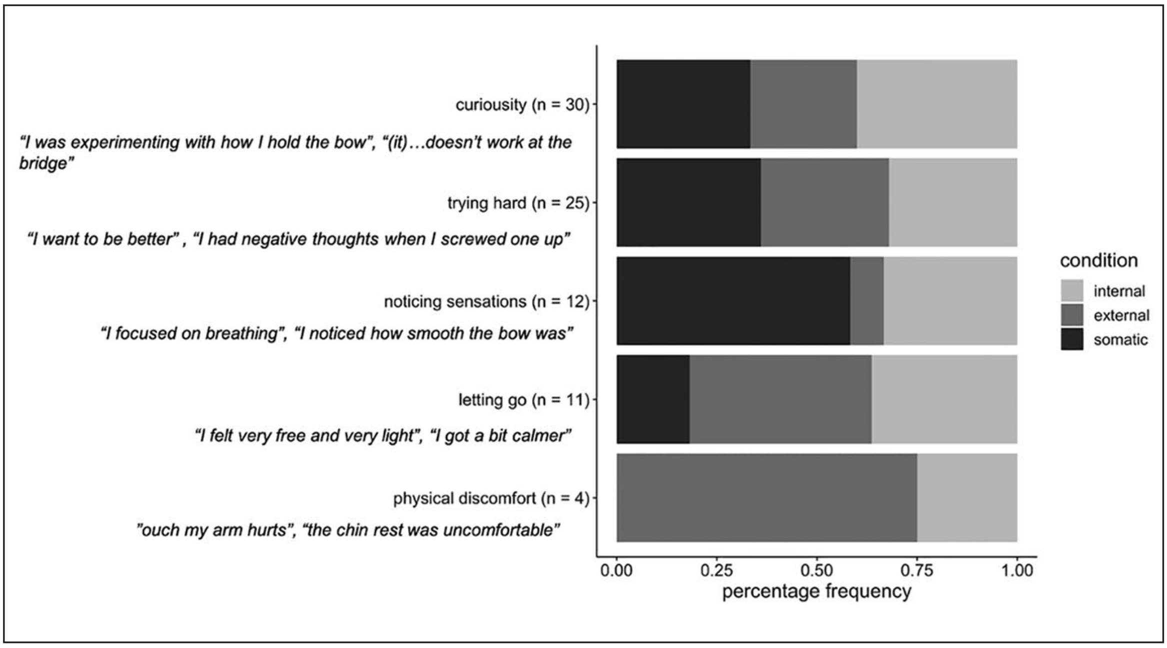

Figure 3. Summary of participants' reported thoughts.
Note. Distribution of focus conditions within comments relating to each theme. The *y*-axis displays each theme derived, with the total number of comments coded as belonging in each theme in brackets, along with two example comments. The *x*-axis displays the frequency, as a percentage, of each focus condition within each theme.

Participants' Reported Thoughts

Figure 3 displays the percentage distribution of participants' comments for each theme across the focus conditions. From these descriptive trends, we can observe that the curious and trying themes are fairly evenly distributed across all three focus conditions. This is a little surprising because we might have expected the internal condition to reflect more frequent trying and less frequent curious comments, in reflection of CAH. On the other hand, the letting go theme appeared mostly in the external and somatic foci, and the noticing sensations theme appeared mostly in the somatic focus, which might indicate changes in thought content related to the focus induced. Because the prevalence of some themes was very low, statistical analysis of these differences was not possible in the current sample.

Some additional insights were noted in these data that can inform further research. For example, one experienced player had the opinion that focus strategies could/should be combined for an optimal performance: "concentrating on the sound combines the two tasks before (i.e., focusing on movement, and string resistance) . . . [you] have to be aware of both to get a good sound." This comment highlights the importance of considering the ecological validity of focus instructions. In addition, some participants seemed to show an intuitive understanding of constrained action effects, realizing that they had to yield control and declarative knowledge to succeed at the task. For example participants reported: "I had to let go a bit and it worked better than concentrating too hard" and "I find that focusing hard on movement in the arm has the opposite effect of what it should. The arm stiffens up: it's counter-productive." These unprompted reflections on the detrimental effects of the internal focus align with CAH.

Discussion

The results of this study provide partial support for the CAH in the novel context of a slow-motion bow-control task and suggest benefits to bow control of a somatic FOA (a type of external focus) on tactile sensory feedback. We found that the somatic focus improved task performance for experienced string players but not for novices, suggesting that expertise was an influential factor. We also observed that the somatic focus decreased triceps muscle activity compared to internal for both groups, consistent with physiological understandings of constrained action. These findings tentatively suggest that encouraging attention toward tactile feedback through external focus instructions instead of internal movement mechanisms may more optimally support bow-control performance skills, particularly with experienced performers. However, there were no significant differences between the internal focus on arm movement and the external focus on sound, which does not support previous findings that focusing on sound improved music performance (Duke et al., 2011). We also observed no significant effect of attentional focus on number of successful click sounds or on muscle activation in the bicep or deltoid muscles, which was contrary to our hypothesis. Participants' reported thoughts during the experiment provided insight into how aspects of constrained action may or may not be evident in performers' conscious experience.

Task Performance

In partial support of our hypothesis, we found that experienced players made significantly fewer errors under the somatic focus on bow-string resistance compared to the internal focus on arm movement. This result is in line with previous research supporting the CAH in music tasks (Atkins, 2017; Duke et al., 2011; Mornell & Wulf, 2019) and suggests that the bow-control skills essential for quality violin tone production are better supported by a focus on bow-string resistance than a focus on arm movement. However, we found no significant difference in errors between the internal and external foci, suggesting that for this task, a focus on sound was not a beneficial alternative to an internal focus. This finding is in line with our results from a previous study on FOA in a different task of open string bowing (Allingham et al., 2021, in review) in which we similarly found that a somatic focus increased spectral centroid of violin tone and reduced shoulder muscle activity compared to internal focus but that there were no significant differences between the internal and distal external foci.

This result could be interpreted as opposing the *distance effect*, which would have predicted better task performance in the external focus on sound compared to the arguably more proximal somatic focus. This could be an effect specific to violin playing, supporting the notion that attention to tactile sensory feedback can be especially beneficial in instrumental music-making (Stambaugh, 2019), particularly string playing.

Furthermore, this finding may be driven by a similar mechanism to that of Singh and Wulf (2020), who found that for beginner volleyball players, a proximal external focus, which brought attention to the technical means of action execution, was more effective than a distal external focus. In our study, the somatic focus may have allowed performers to concentrate on bow technique while avoiding constrained action effects, whereas the sound focus did not allow this attention to technique and therefore was not helpful. Although Singh and Wulf found this effect only for beginners and not experts, our study used a task that was unfamiliar to both expertise groups, meaning that experienced players may have been responding more like beginners. However, it should be noted that a focus on sound might not necessarily constitute a distal focus given that sound might be experienced as close to the body. Further research is needed to establish whether performers experience a focus on sound as distal or proximal. Furthermore, the lack of FOA effect in our novice group may have been due to poorly established bow technique, wherein a suboptimal bow hold may have made the current task easier, giving the novices an advantage. This explanation would also be in line with our findings that experienced players did not perform better overall than novices.

Another possible explanation of the observed expertise effects is that novices might have felt less pressure to perform well than the experienced players, making them less susceptible to constrained action effects. This would be in line with Gray (2004), who found that experts were more likely than beginners to reinvest procedural knowledge into a task when they were performing poorly in an attempt to learn what they were doing wrong and regain control over task execution. Under this reasoning, the poor performance observed in the experienced group may have been a longer term strategy to learn from their mistakes. Indeed, this explanation would be consistent with our result that experts had overall higher bicep activity than novices, possibly reflecting increases in small elbow flexion movements in attempts to regain control after errors. Further research using the current task in a skill-retention test could investigate whether experts are likely to exhibit similar immediate performance but better skill retention than novices.

Considering in more detail the apparent inefficacy of the external focus in this particular task, we propose a possible explanation in the immediacy of the different feedback sources focused on. For example, focusing on bow-string resistance drew participants' awareness to in-the-moment feedback about string behavior, even possibly highlighting cues about what the string would do next. In contrast, focusing on sound placed participants' attention on more delayed feedback. The increased immediacy of the tactile feedback to which performers attended in the somatic focus may have increased their ability to react quickly enough to avoid errors. This highlights the potential usefulness of a focus on bow-string resistance for supporting technical bowing precision. However, a focus on sound may be more effective in different types of musical tasks, particularly more highly automated tasks.

Another aspect that should be considered is how our external instruction to focus on the sound produced might perform in comparison to a focus on imagined sound. Wulf (2016) argued that FOA instructions given in a sports context affect the preparation stage of action execution, suggesting the idea that an external focus might elicit preparatory visual imagery. In music, a more equivalent type of external focus might be to focus on imagined sound rather than actual sound. Because auditory imagery is widely used in mental rehearsal strategies among musicians (Connolly & Williamon, 2004), it would be interesting to explore how use of auditory imagery may be combined with FOA techniques to optimize music performance. Although our results support the benefits of a somatic FOA over an internal FOA in this specific bow-control task, they also highlight that various types of external focus may have differing effects and that attention to certain kinds of feedback may affect performance. This supports previous findings in music research that a distal external focus does not always improve performance and learning (Atkins & Duke, 2013; Stambaugh, 2017, 2019).

Additionally, we wish to highlight the novelty of these findings in the context of a very slow movement. Because slow movement may cause changes in attentional state (Niksirat et al., 2017), it is possible that the slowness of the task is responsible for the observed benefits of the somatic focus compared to the external one. Further studies on this topic should evaluate FOA effects at differing movement speeds to explore the potential influence of slowness.

Our hypothesis that FOA would increase number of clicks that participants were able to produce was not supported. One explanation for this could be that conscious control elicited by the internal focus caused participants to increase their rate of attempts along with decreasing bow-control ability, resulting in an increase in task success along with the number of errors. Further research could explore how FOA affects pace of behavior or perception of passing time. Nonetheless, our overall results on task performance indicate benefits to bow-control performance of focusing on tactile feedback.

EMG Activity

In line with previous research on the physiological effects of an internal focus, we found significantly increased muscle activity under internal focus compared to somatic for the triceps muscle. However, contrary to our hypothesis, we observed no effect of FOA in the bicep or deltoid muscle. The specificity of this effect to the triceps muscle is presumably due to the nature of the task, which involved only down-bow actions (i.e., triceps muscle use). In sports-based motor-performance research, such differences in EMG activity have been attributed to changes in muscle efficiency. However, in our study, it is difficult to tell whether this result reflects muscle efficiency because we did not control number of movements between conditions. Further research could aim to test efficiency of muscle use in music performance under different FOA by controlling for number of repetitions of a specific movement. Nonetheless, our findings are partially consistent with previous literature that an internal focus causes increased muscle activity relative to external. This finding cautiously supports the notion that a music teacher's verbal instructions drawing attention to internal movement mechanisms may not optimally support efficient muscle use in students. Another useful question for further research would be the relationship between FOA and overuse injuries in musicians. For example, if an external focus causes more efficient muscle use in musicians, FOA might be a useful pedagogical tool for avoiding injuries caused by excess tension.

Participants' Reported Thoughts

Our exploratory analysis of participants' reported thoughts during the experiment provides an initial overview of how FOA might or might not be reflected in performers' conscious thoughts. For example, the letting go theme showed a trend for appearing less often in the internal focus, in line with ideas of constrained action as increased conscious control (Wulf et al., 2001), but the trying hard and curiosity themes did not seem to differ across focus conditions. Further research could look for systematic effects of attentional focus in performers' reported thoughts. It is also interesting that the physical discomfort theme did not appear in the somatic focus condition at all, and further research could explore whether a somatic focus might reduce thoughts about negative physical sensations. In addition, some participants reported a preference to focus on several objects at once, indicating that for some individuals, focusing on one aspect of performance at a time may not be an ecologically valid approach. Finally, some participants communicated an intuitive understanding of the detrimental effects of an internal focus, providing support for the phenomenon of constrained action from an experiential point of view.

Limitations

The generalizability of our findings is limited by the specificity of our sample, which consisted of mainly German, undergraduate, amateur musicians, all of whom specialized in classical music. Further research should aim to sample musicians of various ages, stages, musical genres, and nationalities. Studies of FOA effects in children are particularly relevant to music education research. Also important to music education would be investigating how individual differences, such as personality traits and experience with somatic training methods or mindfulness, may influence FOA effects. For example, training in the ability to observe the body in a nonjudgmental, noncontrolling way might limit the detrimental effects of an internal focus (Mattes, 2016). Our findings are also limited to the particular task we chose to study, which was a reductive technical exercise (albeit, a pedagogically relevant task) rather than a fully expressive musical performance. Only one rater carried out the audio analysis, which may affect the generalizability of these findings. However, the assessment of task performance through both audio and visualization of the signal improved the objectivity of this measure. A next important step will be to understand the meaningful impact this effect might have on real-life violin performance skills. Expressive music performance requires a distinct set of sensorimotor and cognitive skills in comparison to technical exercises (Kenny, 2011) and thus may necessitate a different optimal FOA. An abundance of musical tasks remains to be investigated in this context. In particular, FOA effects on intonation skills in string playing, layperson perceptions of expressive performance, and changes to expressive gesture could be particularly interesting. There is also still a need to extend research on FOA effects to the learning of musical motor skills as well as performance (Stambaugh, 2017, 2019) and to apply the FOA paradigm to real music performance situations outside the laboratory and to group music-making contexts.

Pedagogical Implications

The results of our study suggest that focusing on internal movement mechanisms may be detrimental to the performance of a violin bowing motor task, whereas a focus on tactile sensations through the bow may be beneficial. The bow-control task used in the current study is based in a realistic educational exercise that condenses the motor skills necessary for high-quality violin sound production; therefore, our findings are directly relevant to violin teaching approaches. We suggest that promoting a somatic FOA during performance should have a good potential for improving violin bow-control skills. Although further research is needed to test FOA effects in a more applied educational context, the findings presented here can inform and inspire educators to consider the effects that FOA may have in their day-to-day teaching. Trying out different attentional foci in teaching practice is a safe, easy, and potentially powerful educational tool. Building on recent initiatives from music conservatoires to incorporate mental skills and health and well-being training into their curricula (Connolly & Williamon, 2004; Matei et al., 2018), FOA offers a performance psychology technique that can be incorporated easily into everyday lessons and practice. This provides a practical contribution toward the need to equip music students with evidence-based performance skills (Ford, 2013; Shaw et al., 2020). Furthermore, in a learning context, this kind of technique-based external focus could be a useful educational tool to promote implicit or discovery learning (Bakker, 2018; Poolton & Zachry, 2007). For example, by focusing on tactile sensations, the student is encouraged to learn the rules of bow control through interaction with the instrument and without the need for explicit instructions on bow technique. In this way, a somatic focus might also allow teachers to guide students toward understanding the association between physical action and acoustical outcome (Parsons & Simmons, 2020) while avoiding constrained action effects. Indeed, FOA remains a promising music-performance-enhancing technique, deserving the attention of today's music educators.

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Study 3.

Slow practice and tempo management strategies in instrumental music learning: Investigating prevalence and cognitive functions.

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Slow practice and tempo-management strategies in instrumental music learning: Investigating prevalence and cognitive functions

Emma Allingham and Clemens Wöllner

Abstract

Practicing slowly is an intuitive and prevalent learning strategy among instrumental musicians. Nevertheless, little is known about the psychological mechanisms of slow practice, or how rehearsing slow movements may support the performance of fast-tempo playing. This study investigated the prevalence and possible functions of slow practice strategies. A total of 256 adult instrumental musicians provided self-report ratings about slow practice and tempo-management strategy use, musical background information, and the Musical Self-regulated Learning Questionnaire in an online survey. Results indicate that practicing slowly is an extremely common technique among classical (99.45%) and non-classical (89.12%) musicians of varying expertise, supporting both technical and expressive goals, with technical more frequently reported. Principal components analysis identified three types of slow practice as serving expressive, technical, or preparatory functions. Expressive Slow Practice and Technical Slow Practice were positively associated with self-regulated learning, but not expertise across both music genre groups. Preparatory Slow Practice was positively associated with self-regulated learning and expertise in classical musicians, while in non-classical musicians, it had no association with self-regulation and a negative association with expertise. These findings provide groundwork for further research exploring causal effects of slow practice and tempo-management strategies on learning and development of self-regulated learning in various music genre cultures.

Keywords

slowness, motor learning, music practice, self-regulation, expertise

From an early stage in their musical education, aspiring musicians learn a simple approach to tackling difficult material: practicing slowly. Learning to play music is learning to craft an art

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form in real time; thus, manipulating tempo may provide a useful strategy for musicians in building both motor skills (Donald, 1997; Henley, 2001) and intellectual understanding of the music (Chaffin et al., 2003). Slowness in music practice may take the form of slow movement exercises, particularly for developing tone control in woodwind, brass, or string instruments (Galamian, 1962; Schorr-Lesnick et al., 1985; Waddell, 2002), but in the current study, we investigate a specific form of slow practice common to all instruments: practicing musical material slower than its intended performance tempo.

While slow music-practice is a commonly known practice technique, little is understood about the functions of slow practice from a psychological perspective. Slow practice is likely used by both novice (Austin & Berg, 2006) and experienced (Chaffin et al., 2003) musicians, but the different roles that slow practice might play in various stages of learning are unknown. Furthermore, general belief that slow practice is the optimal starting point for learning unfamiliar material may not be supported by empirical data (Donald, 1997). Another pertinent question is how rehearsing slowly may support the learning of fast movements which fundamentally differ in motor organization and sound quality compared to their slowed-down versions (Goebl & Palmer, 2008; Winold et al., 1994). This study aims to address this gap in the literature by investigating how and why instrumental musicians use slow practice and tempo management to achieve their musical goals, and the possible cognitive functions that slow practice may play in learning.

Slow practice in music research

Practicing slowly is often valued as a sophisticated rehearsal approach. One example of this is the extremely slow practice of virtuoso pianist Sergei Rachmaninov. His student Abram Chasins described this practice as lowering the tempo so drastically as to render the music unrecognizable, and attributed this strategy to Rachmaninov's dedication to precision and perfection (Chasins, 1961). In music research, little is known about the many possible ways musicians use slow practice, although some studies have touched upon the topic. Slow practice with gradual tempo increase has been reported as a frequent teaching strategy (Barry & McArthur, 1994) and is commonly used among undergraduate instrumentalists (Smith, 2005). Similarly, slow tempo in music practice has been reported as often used among 11- to 12-year-old music learners (Austin & Berg, 2006) and music education undergraduates (Byo & Cassidy, 2008).

Slow practice has further been considered an indication of systematic or structured practice. For example, Barry (1992) included slow practice as a key component of their *structured practice* intervention, which also involved musical analysis and mental practice. They found that, in children learning brass and woodwind instruments, structured practice better improved accuracy and musicality compared to free practice. Slow practice may have played an important role in this improvement. Similarly indicating a link between slow practice and structured practice, questionnaire studies have found that rating items relating to slow practice loaded highly onto a factor representing systematic practice strategies (Hallam et al., 2017, 2020). Thus, slow music learning strategies are likely indicative of practice that is planned and organized.

Considering a deeper look at possible functions of slow practice, research on expert musicians has provided some preliminary ideas. Nielsen (2001) found evidence of slow practice in two experienced organ players, showing that one player used slow practice to improve accuracy, while another combined accuracy with rapidity goals by incorporating fast hand movements into a slow tempo. Furthermore, Chaffin et al. (2003) found that an expert concert pianist used slow practice in an initial run-through of a new piece to tackle technical difficulties, establish structural knowledge, and evaluate performance markings. These findings show that slow practice may be employed by expert players and might involve high-level musical goals as well as basic motor control outcomes.

Tempo-management strategies

Slow practice may be particularly useful for learning technically difficult fast passages, which place a high information load on working memory resources. An alternative strategy for dealing with such sections is *chunking*, in which the learner divides the music into manageable sections (e.g., Prichard, 2017). In this way, a fast tempo may be maintained within chunks, while pauses allow time to prepare for the next section. Another strategy for dealing with fast passages is practicing note patterns in varying rhythms (e.g., Hallam, 1995), which may help the performer by allowing individual note changes to be rehearsed at different speeds. These three strategies provide different ways to insert extra time into musical material during practice, and thus can be considered *tempo-management strategies*. Little is known about how common or effective these techniques are in comparison to slow practice.

Another aspect of tempo management during practice is the organization of different tempi. Utilizing only slow practice is unlikely to improve fast performance (Pierce, 2006); therefore, slow practice is probably often used in conjunction with faster speeds. Jørgensen (2004) described two main strategies of tempo organization relating to slow practice: starting slowly with a gradual tempo increase and alternating between fast and slow tempi. Although gradually increasing tempo may seem intuitive, Donald (1997) found evidence that alternating tempi resulted in more efficient learning of piano scales. As tempo changes may affect a musician's motor system organization (Dahl et al., 2011; Goebl & Palmer, 2008; Winold et al., 1994), the alternating tempo strategy may benefit learning by preparing the motor system for the final tempo early in the learning process (Donald, 1997). However, Henley (2001) was unable to replicate this finding in high-school aged woodwind and brass students; thus, generalizable effects of tempo organization remain to be explored.

A further possible tempo organization technique is playing at different tempi in a random order, which may benefit motor learning (Caramiaux et al., 2018) through a process known as *contextual interference* (Shea & Morgan, 1979). The contextual interference effect describes an improvement to motor skill learning when practicing tasks in a mixed-up order, rather than perfecting one task before moving on to the next (Farrow & Buszard, 2017). However, the degree to which this technique benefits learning may depend on the characteristics of the tasks and the individual learner (Magill & Hall, 1990). Initial support for benefits of contextual interference in music learning has been shown, although further research is required in order to generalize such effects (Carter & Grahn, 2016; Stambaugh, 2011). Thus, investigating the prevalence of these three tempo organization strategies will inform further empirical testing of their efficacy in a musical context.

Cognitive functions of slow practice

The cognitive functions of slow practice are not well understood. A likely possibility is that slow practice makes difficult tasks more accessible by reducing cognitive load during learning. In this context, reducing cognitive load can be seen as a simplification in learning, affecting perceived object difficulty and attentional demands. For example, the reduction of speed can benefit training of bimanual coordination (Magill, 2011, p. 417), and music perception research has shown that high cognitive load diverts attention from a musical task, leading to underestimations of time durations (Brown & Boltz, 2002; Wöllner & Hammerschmidt, 2021). Learning to play a new piece of music requires large amounts of information to be quickly processed in working memory (Roden et al., 2014), and slow practice is one method of reducing this working memory load while still taking in all of the musical information. Slow, holistic processing of musical material might also help to stimulate germane schema-building processes important to learning (de Jong, 2010).

From a perceptual-motor skills perspective, slow practice may be useful during the early *associative phase* of skill acquisition, in which feedback is particularly important (Rosenbaum, 2010). For example, slow movement may allow continuous processing of feedback where fast movement does not (Hay & Bard, 1984), thus providing a necessary learning step before motor control becomes automatized. This view would imply that once musical material has been established in long-term memory (i.e., automatic motor control), slow practice is no longer required. Therefore, we might assume that slow practice is associated with the early stages of learning musical material and with beginners more than expert players (cf. Gentile, 2000). Conversely, for sound-sustaining instruments, slow practice may be more difficult for less experienced players (Maxfield, 2018) and might be avoided in the early learning stages. Advanced wind, brass, or string instrumentalists might also use slow practice as a way of working on tone production (Galamian, 1962; Schorr-Lesnick et al., 1985; Waddell, 2002). For furthering understandings of the cognitive functions of slow practice, it would be useful to know what goals musicians have when they practice slowly and what specific musical features they aim to improve through slow practice.

Slow practice may also be understood as a self-regulatory practice behavior. Self-regulated learning is defined as the active management of one's own learning, involving planning, goal-setting, strategy selection, and self-assessment; and is considered an important ingredient of successful music practice (McPherson & Renwick, 2011). Advanced music students tend to exhibit highly self-regulated practice (Nielsen, 2001), and instruction in self-regulation may increase performance achievement (Miksza, 2015). Slow practice appears to exemplify a self-regulated behavior, as the purposeful selection and maintenance of an optimal practice tempo would require forethought, planning, and self-assessment, which are key ingredients of self-regulation. Thus, use of slow practice may require the ability to self-regulate. In addition, establishing slow practice as a regular part of a practice routine might help to improve a learner's self-regulatory capabilities. Investigating the relationship between slow practice behaviors and self-regulated learning as a psychometric trait (Ritchie & Williamon, 2013) provides a starting point for further understanding the possible self-regulatory functions of slow practice.

The current study

The current study aimed to broadly investigate the prevalence and possible cognitive functions of slow instrumental music practice, with the goal of informing psychological understandings of music learning. Furthermore, although the contexts and environments of music practice, as well as the perceived value of different skills, have been found to differ across musical genres (Creech et al., 2008; Gruber et al., 2004), the majority of previous research addressing the psychology of music practice has focused on Western classical music only (Jørgensen & Hallam, 2011). Therefore, we further aimed to explore how use and functions of slow instrumental music-practice may depend on the musical performance genre of the musician. Exploring possible genre-related differences in practicing has direct pedagogical value for higher music education where there is a need to understand music education approaches beyond the context of classical music (Welch et al., 2008). To this end, we employed a quantitative, self-report questionnaire study, sampling musicians from a wide range of experiences and backgrounds (e.g., professionals, amateurs, music students).

The research questions were as follows:

RQ1. How prevalent, among instrumental musicians, is the use of slow practice in general, as well as specific techniques of practicing slowly and managing tempo?

RQ2. Why do instrumental musicians use slow practice?

RQ3. When, in the musical learning trajectory, is slow practice used by instrumental musicians?

RQ1 was addressed through analyzing reported frequency of use of certain practice techniques, while RQ2 was addressed via reported goals during slow practice and exploring relationships of slow practice with self-regulated learning. Finally, RQ3 was addressed by exploring associations of slow practice with musical expertise.

Methods

Respondents

In total, 362 responses were collected from an online questionnaire administered through the SoSci platform and advertised online. Data were screened for completeness, uniqueness, quality (i.e., sufficient variation in ratings), and logical consistency; 102 respondents were excluded due to incompleteness of data. A further three participants who reported ages under 18 were excluded, and a final respondent was excluded for lack of variation and logical consistency in their ratings. Therefore, 256 respondents (132 female, 122 male, 2 other) were retained for analysis, all of whom played a musical instrument (M years of lessons = 10.18, SD = 7.41). No incentives were offered for filling out the questionnaire.

Respondents were aged between 18 and 77 years (M = 43.49, SD = 16.44) and were of 43 different nationalities; 113 were self-identified amateur musicians, 73 professional performers, 32 music teachers, 27 music students, and 11 "other professional musicians." Reported genres of music played included classical (182), pop/rock/blues (30), folk (27), and jazz (17). To analyze the effects of musical performance genre, respondents were categorized into two groups: classical (n = 182) and non-classical (n = 74). Instruments played included bowed strings (140), woodwind (37), keyboard (31), plucked strings (33), brass (9), percussion (5), and accordion (1).

Materials and procedure

The questionnaire collected ratings on 7-point scales in response to questions about practice behaviors and goals. This included rating the frequency of a particular behavior from *almost never* to *almost always*, or the amount of time usually spent on a particular practice strategy from *almost none* to *almost all*. Respondents also rated how confident they felt (*not confident at all* to *very confident*) at sight reading, playing from memory, and improvising. Respondents were asked, "Do you use slow practice?" with a yes/no response option, and filled out the Musical Self-regulated Learning Questionnaire (Ritchie & Williamon, 2013). Information about musical background and demographics was also collected. Further data not analyzed in the current article included questions about mental practice and experienced flow during slow practice, as well as free-written answers and comments. The study was approved by the Ethics Committee of the Faculty of Humanities, University of Hamburg, and participants gave their informed consent before taking part.

Data analysis

Analyses were carried out in RStudio software, Version 1.3.1093. All variables were screened for extreme univariate outliers such that values outside the limits of three times the interquartile range above or below the second and fourth quartiles were excluded (Tukey, 1977). First, prevalence and goals of slow practice were assessed via analyses of variance (ANOVAs) of rating items, with factors Genre (classical or non-classical musician), and Technique or Goal (i.e., the different rating items). We report Greenhouse–Geisser corrected degrees of freedom, where Mauchly's test of sphericity was statistically significant, and Bonferroni corrected post hoc tests to follow up significant main effects. In addition, we ran single-sample *t* tests on rating items of slow practice goals and techniques to establish whether they were rated significantly higher or lower than the midpoint of the rating scale. To reduce the variable set for further regression analyses, we carried out a principal components analysis (PCA), which is a method of uncovering latent variables within a dataset, emerging from a statistical analysis of the data, rather than pre-established theoretical ideas (Tabachnik & Fidell, 1983). We ran a PCA with Oblimin rotation on ratings of practice behaviors (both slow practice and general practice) and confidence in different musical skills. We then derived PCA scores using the regression method, in which participants' original ratings were weighted based on component loadings, and standardized to have a mean of zero and standard deviation of one (Tabachnik & Fidell, 1983). This resulted in a score for each participant for each principal component. PCA components 1, 3, and 6 appeared to describe types of slow practice because they had high loadings for items related to slow practice goals and techniques, while the remaining components had high loadings for items relating to practice more generally (Table 2). Therefore, we utilized the derived PCA scores of these three components (Expressive, Preparatory, and Technical Slow Practice) to be used as dependent variables in forced entry linear regression models exploring relationships of slow practice components with expertise and self-regulated learning.

Results

Prevalence and methods of slow practice

Out of the total sample ($N=256$), 96.48% of respondents reported using slow practice (99.45% of the classical group and 89.12% of the non-classical group). Further analyses focused on slow practice goals and strategies; therefore, the nine (one classical, eight non-classical) respondents who reported not using slow practice were excluded (new sample, $n=247$).

To address RQ1, we analyzed differences between ratings of how frequently the following techniques were used: practicing under tempo, breaking the music into chunks, and practicing in different rhythms (rated from *almost never* to *almost always*). Results showed a main effect of Genre, $F(1, 244)=10.16$, $p<.01$, $\eta_p^2=.04$, such that classical musicians gave overall higher (more frequently used) ratings ($M=5.35$, $SD=1.85$) than non-classical ($M=4.82$, $SD=2.00$), and a main effect of Technique, $F(1.91, 465.28)=71.30$, $p<.001$, $\eta_p^2=.23$, but no interaction effect, $F(1.91, 465.28)=2.43$, $p>.05$. Pairwise comparisons showed that all three items were significantly different (all *p*s $<.001$), with slow rated as the most used technique ($M=6.07$, $SD=1.18$), followed by chunking ($M=5.28$, $SD=1.73$) and rhythm variation ($M=4.28$, $SD=2.21$) (Figure 1, Panel A). Single-sample *t* tests for each rating item showed that all three techniques were rated significantly higher than the middle of the scale (i.e., they were reported as frequently used, $p<.05$).

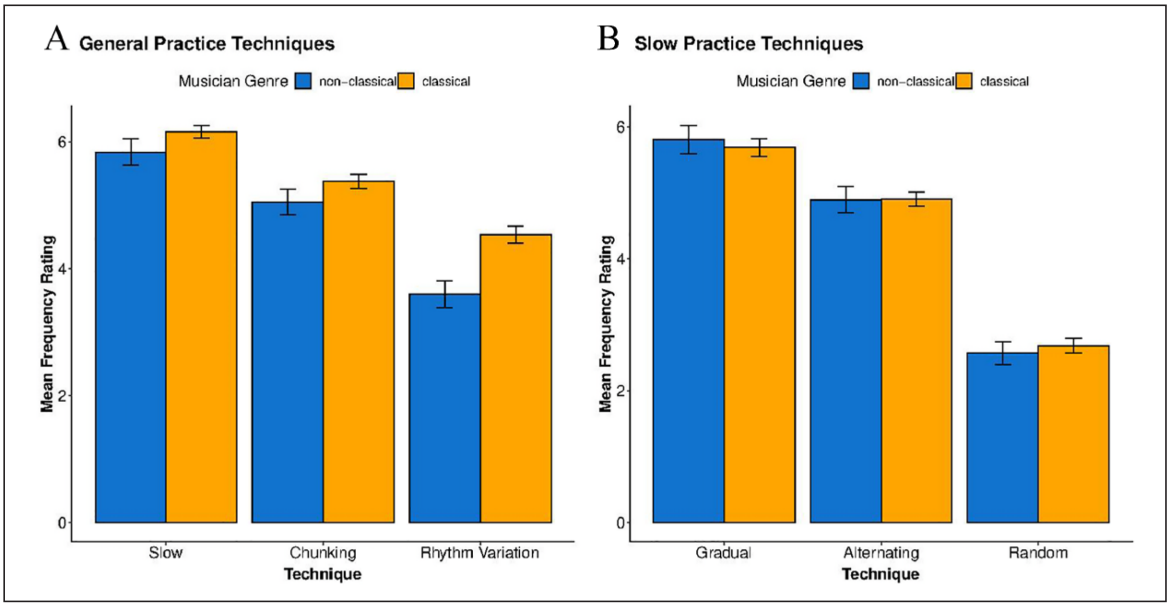

Figure 1. Frequency of Practice Techniques.
Note. The figure displays mean ratings of frequency of general practice techniques (Panel A) and slow practice techniques (Panel B), split by classical ($n = 181$) and non-classical ($n = 66$) musicians. Error bars show the standard error of the mean.

Also addressing RQ1, we compared frequency ratings of the different tempo organization strategies: gradually increasing tempo, alternating between slow and fast tempi, and playing at randomly ordered tempi (rated from *almost never* to *almost always*). There was a main effect of Genre, $F(1, 245) = 6.19$, $p < .05$, $\eta_p^2 = .03$, such that classical musicians rated techniques overall as more frequently used ($M = 4.54$, $SD = 2.17$) than non-classical ($M = 4.10$, $SD = 2.32$), and a main effect of Technique, $F(1.90, 465.21) = 195.50$, $p < .001$, $\eta_p^2 = .44$, but no interaction effect, $F(1.90, 465.21) = 0.26$, $p > .05$. Pairwise comparisons showed that all three items were significantly different ($p < .001$), with gradual increase rated as the most used technique ($M = 5.72$, $SD = 1.66$), followed by alternating tempi ($M = 4.90$, $SD = 1.89$) and random tempi ($M = 2.65$, $SD = 1.84$) (Figure 1, Panel B). Single-sample *t* tests for each item showed that gradually increasing tempo and alternating tempi were rated significantly higher than the midpoint of the scale (frequently used, $p < .001$), while random tempi was significantly lower than the midpoint (infrequently used, $p < .001$).

Goals of slow practice

Addressing RQ2, we investigated whether respondents more commonly reported adopting technical or expressive goals during slow practice. Therefore, we compared ratings of how frequently performers' reported goals during slow practice were "to work on expression" or "to work on technique" (rated from *almost never* to *almost always*). Results showed a main effect of Goal, $F(1, 243) = 132.31$, $p < .001$, $\eta_p^2 = .35$, such that Technical goals ($M = 6.19$, $SD = 1.01$) were rated significantly higher than Expressive ($M = 4.62$, $SD = 1.69$). There was no main effect of Genre, $F(1, 243) = 1.21$, $p > .05$, and no interaction effect, $F(1, 243) = 0.18$, $p > .05$. Single-sample *t* tests for each item showed that both technical and expressive goals were rated significantly higher than the midpoint of the scale (both frequently used, $p < .001$).

Table 1. Ratings of Slow Practice Goals.

Item (goal of slow practice)	Classical musicians (n = 156)	Non-classical musicians (n = 53)
	M (SD)	M (SD)
Intonation	6.47 (0.88)***	6.21 (0.97)***
Articulation	5.47 (1.51)***	5.40 (1.39)***
Rhythm	5.17 (1.68)***	4.98 (1.56)***
Dynamics	4.06 (1.77)	4.09 (1.84)
Structure	4.45 (1.89)**	4.98 (1.45)***
Memory	3.42 (2.01)***	4.40 (2.16)

Note. The p-value indications are for single-sample t tests, in comparison to the midpoint of the scale (4).
**$p < .01$. ***$p < .001$.

To examine slow practice goals in more detail, we analyzed ratings of more specific goals (intonation, rhythm, articulation, dynamics, structure, and memory), each rated from *almost never* (adopted) to *almost always* (adopted); 38 participants whose instrument did not enable intonation control (e.g., piano, percussion) were excluded, in order to be able to include intonation work as a goal. Results showed a significant main effect of Goal, $F(4.33, 895.86) = 66.06$, $p < .001$, $\eta_p^2 = .24$, and a significant interaction of Goal and Genre, $F(4.33, 895.86) = 4.76$, $p < .001$, $\eta_p^2 = .02$, but no main effect of Genre, $F(1, 207) = 1.06$, $p > .05$. The interaction was followed up with a simple effects analysis, showing a main effect of Goal for classical musicians, $F(4.34, 672.15) = 94.67$, $p < .001$, $\eta_p^2 = .38$, and for non-classical musicians, $F(3.97, 206.50) = 15.31$, $p < .001$, $\eta_p^2 = .23$. Pairwise comparisons in the classical group showed that the goal of intonation work was rated as significantly more frequently adopted than all other goals (all ps $< .001$). Articulation and rhythm goals were rated as significantly more frequently adopted than the remaining goals ($p < .001$), followed by dynamics and structure ($p < .01$), while the goal of memory was rated as significantly less frequently adopted than all other goals (all ps $< .01$). For non-classical musicians, the goal of intonation was also rated significantly more frequent than all other goals (all ps $< .01$), dynamics was rated significantly less frequent than articulation ($p < .001$) and structure ($p < .05$), and articulation was rated significantly more frequent than memory ($p < .05$).

Single-sample t tests for each item showed that intonation, rhythm, articulation, and structure were rated significantly higher than the midpoint of the scale for both genre groups (frequently used). For both groups, dynamics and memory were not rated significantly higher than the midpoint, while memory was rated significantly lower for the classical group (infrequently used; see Table 1).

Dimensions of slow practice

We conducted a PCA on the ratings data in order to reduce the number of variables and to explore the underlying structure of the data. The Pearson correlation matrix of all 29 variables was first inspected, and one variable was excluded from the analysis, due to having no correlations $>.30$. A further four variables were later dropped due to cross-loadings with a difference between components of $<.10$, and a further three due to component loadings $<.55$. On the final dataset of 21 variables, the Kaiser–Meyer–Olkin measure of sampling adequacy was 0.72 (higher than the acceptable level of 0.5), indicating that the data were suitable for PCA, and Bartlett's test of sphericity was significant, $\chi^2(210) = 1{,}570.89$, $p < .001$, indicating adequately high correlations between items for PCA (Field et al., 2012). Seven components were retained based on Eigenvalues > 1 and scree plot inspection. Table 2 shows the PCA weightings.

Component 1: Expressive slow practice. Component 1 is related to the adoption of slow practice goals concerned with cultivating musical expression, with high loadings for working on expression, concentrating on the emotions in the music, understanding or expressing musical structure, working on dynamics, and concentrating on how the music sounds during slow practice.

Component 2: Performance confidence. Component 2 is related to confidence in several performance- and practice-related skills, with high loadings for confidence in sight reading, problem solving during practice, and performing under pressure. It also received a high negative loading for difficulty returning to tempo.

Component 3: Technical slow practice. Component 3 is related to technical goals, with high loadings for working on technique and working on correct notes/intonation, during slow practice as well as frequency of simple slow practice techniques of practicing at a slow tempo, and gradually increasing the slow tempo.

Component 4: Deliberate practice. Component 4 is related to deliberate practice, with a high loading for practicing with defined goals and a high negative loading for practicing without defined goals.

Component 5: Memory confidence. Component 5 is related to confidence in performance skills requiring playing from memory or without a score, with high loadings for confidence in musical improvisation and playing from memory.

Component 6: Preparatory slow practice. Component 6 is related to use of slow practice to prepare for performance or for further practice, with high loadings for using slow practice to warm up the muscles and to calm the nerves before a performance.

Component 7: Tempo variation practice. Component 7 is related to using tempo variation as a practice technique, with high loadings for playing at different tempi in a random order and alternating between performance tempo and slow tempo.

Associations of slow practice with expertise, self-regulated learning and genre

We ran three linear regressions for each PCA component relating to slow practice: Expressive Slow Practice, Technical Slow Practice, and Preparatory Slow Practice. Independent variables were years of musical training (Expertise), Musical Self-regulated Learning (MSRL), and Genre (classical/non-classical), with interaction terms for Genre with Expertise and Genre with MSRL. The years of training variable has been found to be highly correlated with musical sophistication and musical identity (Zhang & Schubert, 2019), and thus should provide a reasonable measure of musical expertise. However, for unusual cases or self-taught musicians, this may not be the case. Therefore, the years of training variable was screened for consistency with other responses and 21 respondents were excluded on the basis that years of training could not accurately gauge their true expertise. For example, professional classical musicians with <10 years of training were excluded, in accordance with expertise theory (Ericsson et al.,

Table 2. PCA Rotated Component Matrix.

	Components						
	1	2	3	4	5	6	7
Eigenvalue	3.27	1.96	1.83	1.82	1.77	1.61	1.49
% of variance	24%	14%	13%	13%	13%	12%	11%
Cronbach's α	.86	.65	.57	.83	.74	.70	.60
Questionnaire items							
During slow practice, my goal is to work on dynamics	**0.74**	−0.03	0.11	0.14	0.04	−0.01	−0.07
During slow practice, my goal is to concentrate on how the music sounds	**0.74**	−0.02	−0.03	0.07	0.03	0.04	−0.06
Confidence sight-reading music	−0.01	**0.75**	0.02	−0.06	−0.19	0.12	0.06
Confidence solving a problem in your music practice without help from someone else	−0.05	**0.67**	0.06	0.14	0.25	−0.02	0.04
How difficult is it returning to the performance tempo after practicing slowly?	−0.10	**−0.66**	0.09	0.07	−0.04	0.09	0.15
Confidence performing music under pressure	0.05	**0.64**	−0.03	0.19	0.13	−0.07	0.07
During slow practice, my goal is to work on technique	0.07	−0.02	**0.72**	−0.02	0.15	0.09	0.15
How often do you start at a slow tempo and gradually increase?	−0.11	−0.05	**0.72**	0.10	−0.01	−0.10	0.14
How often do you practice at a tempo slower than the performance tempo?	−0.04	0.03	**0.62**	0.03	−0.15	0.00	0.29
During slow practice, my goal is to work on correct notes or intonation	0.20	0.08	**0.55**	−0.16	−0.10	0.14	−0.30
How often do you practice without defined goals?	0.00	0.03	0.04	**−0.94**	0.09	0.03	0.02
How often do you practice with defined goals?	0.03	0.08	0.06	**0.87**	0.06	0.10	0.00
Confidence in musical improvisation	−0.07	0.06	−0.04	−0.07	**0.88**	0.07	0.04
Confidence performing from memory	0.10	−0.01	−0.05	0.02	**0.86**	−0.05	−0.01
During slow practice, my goal is to warm up my muscles	−0.01	−0.06	−0.07	0.02	0.07	**0.91**	0.01
During slow practice, my goal is to calm my nerves before a performance	0.04	0.06	0.11	0.05	−0.07	**0.79**	0.04
How often do you play at various tempi in a random order?	0.11	−0.05	−0.02	0.02	0.13	0.04	**0.77**
How often do you alternate between the performance tempo and a slower one?	0.07	0.10	0.07	−0.05	−0.10	0.06	**0.75**

Note. Loadings >.55 are shown in bold. PCA = principal components analysis.

Table 3. Linear Regression Results.

	β	*SE* β	β (standardized)	*p*
Expressive Slow Practice				
Intercept	−.11	.09	.00	.27
Expertise	.004	.02	.02	.79
Genre	.15	.19	.06	.42
Musical self-regulation	.03	.01	.33	<.001***
Expertise × Genre	.05	.03	.14	.11
Self-regulation × Genre	.02	.01	.12	.08
Technical Slow Practice				
Intercept	−.02	.10	.00	.87
Expertise	.02	.02	.09	.32
Genre	.16	.12	.07	.42
Musical Self-regulation	.02	.01	.25	.001**
Expertise × Genre	−.01	.03	−.02	.86
Self-regulation × Genre	.01	.01	.03	.71
Preparatory Slow Practice				
Intercept	−.28	.09	.00	.003**
Expertise	−.01	.01	−.08	.38
Genre	.59	.19	.25	.002**
Musical self-regulation	.03	.006	.27	<.001***
Expertise × Genre	.09	.03	.26	.003**
Self-regulation × Genre	.03	.01	.13	.048*

*p < .05. **p < .01. ***p < .001.

1993), as well as participants who reported 0 years of training, who were assumed to be self-taught. A final participant was excluded as an outlier on this variable; thus, the final sample size for the regression analysis was $n = 255$.

Expressive slow practice. There was a significant positive association of Expressive Slow Practice and MSRL, no association with expertise, and no significant interactions (Table 3). The overall model was statistically significant, $F(5, 219) = 9.98$, $p < .001$, $R^2 = .19$, adjusted $R^2 = .17$, and explained 19% of overall variance in Expressive Slow Practice.

Technical slow practice. There was a significant positive association of Technical Slow Practice and Musical Self-regulation, no association with Expertise, and no significant interactions (Table 3). The overall model was statistically significant, $F(5, 219) = 4.44$, $p < .001$, $R^2 = .09$, adjusted $R^2 = .07$, and explained 9% of overall variance in Technical Slow Practice.

Preparatory slow practice. There was a significant positive association of Preparatory Slow Practice and Musical Self-regulation, but no association with Expertise, and significant interactions of Genre with both Expertise and Musical Self-regulation (Table 3). In addition, there was a significant association with Genre, such that being a classical musician, compared to non-classical, was associated with an increase in Preparatory Slow Practice use. The overall model was statistically significant, $F(5, 219) = 10.88$, $p < .001$, $R^2 = .20$, adjusted $R^2 = .18$, and explained 20% of overall variance in Preparatory Slow Practice.

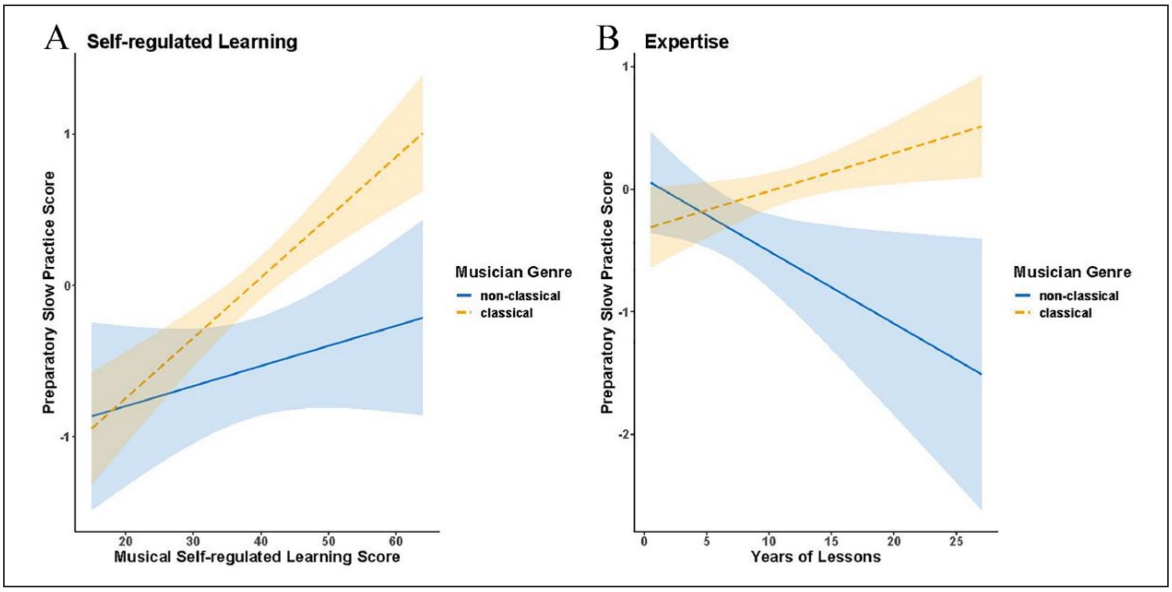

Figure 2. Interaction Effects of Musician Genre, Self-regulated Learning, Expertise, and Preparatory Slow Practice.

Note. The figure displays plots of the interaction effect of Genre with Musical Self-regulation (Panel A), and Genre with Expertise (Panel B) on Preparatory Slow Practice; 95% confidence intervals are shown.

Interactions were followed up with simple slopes analyses. For classical musicians, there was a significant positive association between Musical Self-regulation and Preparatory Slow Practice, $t = 5.53$, $p < .01$, slope estimate = 0.04, $SE = 0.01$, but for non-classical, the relationship was not significant, $t = 1.18$, $p = .24$, slope estimate = 0.01, $SE = 0.01$ (Figure 2, Panel A). This suggests that while classical musicians who report more Preparatory Slow Practice are likely to report higher self-regulated practice, no such relationship exists in the non-classical group.

For classical musicians, there was also a significant positive association of Preparatory Slow Practice with Expertise, $t = 2.68$, $p = .01$, slope estimate = 0.03, $SE = 0.01$, while for non-classical musicians, this association was negative, $t = -2.19$, $p = .03$, slope estimate = –0.06, $SE = 0.03$ (Figure 2, Panel B). This suggests that Preparatory Slow Practice is reported more often by more experienced players in classical musicians, but less often by more experienced players in non-classical musicians.

Discussion

The results of this study indicate that slow music practice is a highly prevalent strategy, with 99.45% of classical musicians and 89.12% of non-classical musicians reportedly using slow practice. We further found that both technical and expressive goals during slow practice were frequently reported, with technical goals reported significantly more often than expressive, and we identified three possible types of slow practice, based on a PCA: technical, expressive, and preparatory. All three types of slow practice were positively associated with self-regulated learning, but not with expertise, while musical performance genre modulated these relationships for Preparatory Slow Practice.

Across both genre groups, slow practice was rated as significantly more frequently used compared to chunking and rhythm variation, although all three strategies were reported as more common than uncommon. This is in line with previous findings that slow practice is frequently used among learners and advocated by teachers (Austin & Berg, 2006; Barry & McArthur, 1994; Byo & Cassidy, 2008; Smith, 2005). Regarding methods of tempo organization, the current findings indicate that across both classical and non-classical musicians, gradually increasing tempo was reportedly the most often-used technique, followed by alternating between two tempi and then practicing at random tempi. This is an interesting finding in the context of motor learning theories, which may suggest gradually increasing tempo to be the least efficient strategy of the three (Caramiaux et al., 2018; Donald, 1997). Thus, prevalent use of gradual tempo increase may not be informed by objective knowledge of the most efficient method. However, there is a lack of empirical evidence for learning benefits of alternating or random tempi in an applied musical context; therefore, further research on this topic would be useful to discern if musicians' practice habits reflect the most effective learning strategies.

Regarding possible functions of slow practice, we found that for both genre groups, technical goals were reported as significantly more common than expressive goals, although both were used frequently. Similarly, in comparing specific goals of slow practice, we found that intonation (a technique goal) was reported as the most prevalent goal of slow practice, across both expertise groups. Descriptively, technical goals of articulation and rhythm were also rated as more frequently used than higher level goals of working on dynamics, structure, and memorization. Overall, these results indicate that slow practice is reportedly used most often to achieve technical, low-level musical goals. This function of slow practice is consistent with the idea of slow practice as important to the early associative phase of motor learning (Gentile, 2000; Rosenbaum, 2010), where slower tempo may allow reduction of cognitive load and detailed attention to feedback in order to improve motor control. In addition, while respondents reported using slow practice to achieve technical goals most often, expressive and higher level musical goals were also frequently reported during slow practice. This finding reflects qualitative descriptions of how advanced musicians may use slow practice to shape expressive ideas (Chaffin et al., 2003). Indeed, use of slow exercises and studies for both tone and expressive skills development was emphasized by flute pedagogue Marcel Moyse, of the French School of Flute Playing (Waddell, 2002), further suggesting that slow practice may support expressive-interpretative functions as well as motor learning.

Further exploring potential functions of slow practice, a PCA revealed three different components relating to slow practice: Expressive Slow Practice, Technical Slow Practice, and Preparatory Slow Practice. This finding provides a foundation for further experimental research attempting to characterize the different types or functions of slow practice that may exist and may encourage music educators to teach diverse ways of using slow practice.

Utilizing multiple regression analyses, we found that all three slow practice components were positively associated with MSRL when performers' musical genre was disregarded. This indicates that musicians who reported more frequently adopting these slow practice strategies tended to report more self-regulation in their music practice, which is consistent with the idea that slow practice strategies may either support or require self-regulation abilities. As self-regulated learning has been associated with musical expertise and performance improvement (Miksza, 2015; Nielsen, 2001), the current results might further suggest that the types of slow practice identified may indicate good quality practice. Establishing causal relationships between slow practice, self-regulation, and learning quality would require further experimental research. For example, would adopting slow practice strategies improve self-regulation, and would those with low self-regulation find slow practice more difficult to employ?

For Preparatory Slow Practice, different patterns of association emerged between classical and non-classical musicians. In the classical group, those who reportedly used more Preparatory Slow Practice tended to have higher reported self-regulated learning and more musical training (positive associations with MSRL and expertise), while in the non-classical group, they tended to have less training (negative association with expertise) and no more or less reported self-regulated learning (no association with MSRL). This finding implies that the characterization of highly expert and highly self-regulated practice may differ between classical and non-classical musicians, suggesting that research on optimal practice strategies should consider the influence of different music genres. However, limitations of the current sample may have influenced these results. For example, the non-classical group encompassed several distinct musical genres, and there was an uneven distribution of types of instrument between groups. Therefore, replication of this study in another sample may yield different results.

No main significant relationships between slow practice components and expertise were found, although we might have expected slow practice behaviors to decrease with expertise if slow practice's main function was during the associative learning phase (Rosenbaum, 2010). This is a finding which may not be surprising to musicians who follow certain advanced pedagogies that advocate the practice of slow exercises and studies (Fischer, 1997; Waddell, 2002). Indeed, it may be the case that experts still employ slow practice in the early phase of learning, an unfamiliar piece of music. Future research could investigate how slow practice is used across the course of learning a new piece.

Several limitations to this study should be considered. For example, the current study did not analyze reported practice behavior differences between musical instruments or gender as has been previously investigated (Hallam et al., 2017, 2020), and the influence of individual differences such as personality on practicing remains to be explored. Indeed, differences in instrument technique may affect the use of slow practice. For example, sustaining instruments such as woodwind, brass, and strings may experience more technical difficulty when practicing long phrases slowly (i.e., running out of breath/bow; Sulliman, 2017) compared to non-sustaining instruments, meaning that novice players may avoid slow practice, while experienced players may use it to develop stamina. Further investigation of the importance of slow practice to specific instrument techniques would be useful. Another possible consideration is differences in slow practice usage between professional and amateur musicians. For example, approaching music practice as an activity to be enjoyed rather than a job to be completed might result in different ways of practicing. Furthermore, the current sample consisted of mainly classical string players; thus, different samples may show different results. Finally, qualitative exploration of this topic may reveal more about musicians' attitudes, opinions, and motivations when using slow practice.

In conclusion, this study provides a first step in investigating prevalence, techniques, and cognitive functions of slow music practice. Our findings that reported use of slow practice was highly prevalent across expertise levels and that diverse musical goals were frequently reported during slow practice challenge the notion that slow practice is only used in the early stages of learning. Furthermore, researchers and music educators might consider possible functions of slow practice as technical, expressive, and preparatory, as highlighted in our PCA results. This study also suggests that further research on causal links between specific types of slow practice and self-regulated learning would be worthwhile. Finally, the differences in reported usage of Preparatory Slow Practice reported here between classical and non-classical musicians indicate the importance of considering how optimal practice and expertise may be characterized differently between various musical genres.

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Study 4.

Putting practice under the microscope: The perceived uses and limitations of slow instrumental music practice.

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Putting practice under the microscope: The perceived uses and limitations of slow instrumental music practice

Emma Allingham and Clemens Wöllner

Abstract

Practising slowly is a commonly used, intuitive approach to music learning, and is widely considered the bedrock of musical skill acquisition. Yet, little is known about the different approaches and techniques musicians use when practising slowly. This study investigated instrumental musicians' perspectives on the uses, limitations, and specific techniques of slow music practice, through qualitative thematic analysis of responses to an online questionnaire. Generally, slow practice was perceived as a useful, and often necessary, part of learning. Furthermore, we identified four perceived functions of slow practice. They were: managing information load; building a foundation for motor learning; creative and critical problem solving; and regulating emotional, mental and perceptual states. We propose a possible underlying mechanism of these functions: reduction of extrinsic cognitive load and stimulation of germane cognitive processes. Respondents also perceived potential technical-practical and emotional-cognitive malfunctions of slow practice, as well as possible strategic pitfalls of using slow practice. Specific techniques of slow practice included use of tempo organisation methods, and strategies to complement slow practice. This provided insight into how biomechanical differences between slow and fast playing might be bridged. Findings have implications for music education and understanding the psychology of musical skill acquisition.

Keywords: slow music practice, cognitive load, motor learning, skill acquisition, thematic analysis

The secrets of fast, virtuosic music performance have captivated the interest of laypeople and researchers for many years (Furuya et al., 2015). Yet anecdotally, elite musicians extol the virtues of practising slowly (Kageyama, 2021). As temporal aspects of motor control, and nuanced musical timing details are key to successful music performance (Repp, 1998; Ullén et al., 2015), the question of how musicians utilise slowness in practice to achieve performance goals is relevant to both psychologists and educators. Indeed, slow practice might be thought of as holding a magnifying glass or microscope to one's playing. This is depicted in the German word for slow-motion "Zeitlupe", literally translating as "time-magnifying lens".

Slow practice is a common strategy in music learning (Barry & McArthur, 1994), and certain types of slow practice have been associated with musical expertise and self-regulated learning (Allingham & Wöllner, 2022). This suggests that slow practice may play a role in achieving musical excellence. Nonetheless, surprisingly little research exists on possible uses of slow practice, and its underlying mechanisms. Accordingly, qualitative research can provide a useful framework with which to understand individualistic nuances of music practice (Hallam, 1995), informing understandings of optimal practice strategies. The current study aims to explore musicians' perspectives and approaches to slow music practice through qualitative thematic analysis of online questionnaire responses, considering possible mechanisms of slow practice in terms of cognitive load theory (CLT) and aspects of motor learning. For the current study, we operationalise the term *slow practice* as: practising music slower than the intended performance tempo.

Cognitive load, automaticity, and flow

CLT provides a useful theoretical structure for examining mechanisms of slow practice. CLT proposes that novel information is processed through a limited capacity working memory (WM), before moving to unlimited long term memory where information schemas are stored (Paas & Sweller, 2012). If the information load involved in learning exceeds WM capacity, information processing becomes impaired and the learner is likely to make mistakes (Lemaire, 1996). Teaching aims to promote schema building in long-term memory, involving three types of cognitive load (Owens & Sweller, 2008). *Intrinsic CL* describes the innate difficulty of a task, which places demands on WM. Learning music involves the interaction of many elements (rhythm, pitch, dynamics etc.), and thus has a high intrinsic CL. *Extrinsic CL* describes difficulty caused by instructional technique. Playing piano music one hand at a time reduces extrinsic CL. Finally, *Germane CL* consists of schema building processes, as information is solidified in long-term memory. Memorising music, for instance, involves a high germane CL, as information schemas representing the music have to be constructed in long-term memory. These three types of cognitive load provide a structure for considering music learning.

Slowing tempo during music practice might affect extrinsic and germane CL. To illustrate, reducing tempo spreads intrinsic CL across a longer time-span, thus allowing the musician greater cognitive capacity to stimulate germane CL. This may support the updating of schemas with more accurate motor plans, and technical solutions to problems. In line with this reasoning, qualitative research on expert musicians has shown that slow practice is used for improving accuracy, tackling technical difficulties, solving problems (Chaffin et al., 2003; Nielsen, 2001). Thus, a possible cognitive function of slow practice is to reduce extrinsic CL and stimulate germane CL.

These CL mechanisms during slow practice may be related to the avoidance of errors. As previously discussed, slow playing likely minimises extrinsic CL, reducing the chance of mistakes (Lemaire, 1996). This approach is connected to the idea of errorless learning; a pedagogical concept in which learners select tasks that they are able to execute without making mistakes, under the reasoning that errors impede learning (Kruse-Weber & Parncutt, 2014). Indeed, Byo & Cassidy (2008) observed this use of slow practice in music students to find an “errorless tempo” (p.38). Errorless learning in motor tasks is thought to support implicit learning (i.e., learning without verbalisable knowledge, Wong & Lim, 2019), and may improve performance under pressure (Maxwell et al., 2001). This approach may also have a positive emotional impact on the learner and boost motivation (Pickard, 2021).

The reduction of extrinsic CL may also be seen as optimising the difficulty of a task to match the skills of the learner. This skill-challenge optimisation is a key component of achieving *flow*; a state of consciousness in which a person is totally absorbed in performance, experiencing effortless control (Csikszentmihalyi, 1990). Thus, flow states might be encouraged by slow practice through cultivating an optimal skill-challenge balance. Another key component of flow is receiving immediate feedback on progress (Nakamura & Csikszentmihalyi, 2009). This may also be supported by slow playing, facilitated by increased time to process auditory and tactile feedback (Hay & Bard, 1984). Flow has been shown to correlate with confidence (Stavrous & Zervas, 2004), and intrinsic motivation for an activity (Martin & Cutler, 2002), and may benefit performance skills (Spahn et al., 2021). Therefore, utilising slow practice to support flow experiences might in turn benefit confidence, motivation, and performance skills. Furthermore, the slow movement component of slow practice may induce relaxation (Niksirat et al., 2017), and encourage mindful presence in the moment such as in Tai chi (Lin et al., 2006) or the Feldenkrais somatic training method (Clark et al., 2015). Thus, slow practice might support pleasurable experiences, fostering motivation and improving wellbeing (Lee et al., 2017).

Also related to CL in music practice is the degree of automaticity in motor processes. Fast movements have been associated with higher automaticity (Fujiyama et al., 2013) and therefore less conscious control and lower intrinsic CL than slow movements. Thus, slow playing might encourage conscious attention to motor skills. This might be useful when schemas in long term memory require updating for refining technique or musical interpretation. Similarly, this approach could support memorisation processes. For example, conscious attention to playing is required for establishing declarative musical knowledge as a memorisation strategy (Chaffin et al., 2009). Bringing conscious attention and increased cognitive load to motor control through slow practice might enable learners to update schemas, even after initial motor learning has been established. On the other hand, directing attention toward automatized body movement has been shown to impair motor performance (e.g., Allingham et al., 2021; Duke et al., 2011; Wulf, 2013). Therefore, while utilising slow practice to increase conscious cognition might support long-term learning, it might also cause poorer immediate performance.

Motor control in slow practice

An interesting question about slow practice is how learners transition from slow to fast playing. Research has shown that tempo may affect motor system organisation in drummers (Dahl et al., 2011), pianists (Goebl & Palmer, 2008) and cellists (Winold et al., 1994). That is, changing the tempo of the music might alter instrument technique, meaning that slow practice might not help the performer to play at a faster tempo. Furthermore, research on motor control at different speeds has shown that slow movement can be more difficult to control than fast movement (Fujiyama et al., 2013; Van Der Wel et al., 2009). Therefore slow practice might create more difficulty for learners. As a solution to this problem, non-slow practice techniques may provide better solutions for developing fast motor control. For example, breaking the music into small sections but maintaining fast tempo (i.e., chunking; Prichard, 2017), or practising fast passages in different rhythmic patterns (i.e., rhythm variation; Hallam, 1995).

Further research is needed to understand how slow practice may or may not support development of fast instrument technique.

The current study

The current study aimed to qualitatively explore instrumental musicians' perspectives on the possible functions and limitations of slow practice in music learning. Qualitative data for the current study was collected in an online questionnaire about slow music practice alongside quantitative rating items. The questionnaire aimed to capture a range of perspectives from a diverse sample of musicians. In a previous study (Allingham & Wöllner, 2022), we analysed the quantitative questionnaire data. In the current paper, we build on this previous work, by qualitatively considering participants' motivations and goals of slow practice. The qualitative questionnaire data provides more contextualised, in-depth responses, and enables us to further explore perceptions of the limitations of practising slowly. The research questions were:

RQ 1: Among instrumental musicians, what are the perceived uses and limitations of slow practice?

RQ 2: What specific techniques of slow practice do instrumental musicians perceive to be useful or not useful?

Utilising a qualitative thematic analysis (Braun & Clarke, 2006), we aimed to provide insight into possible mechanisms of slow practice, through the perspective of cognitive load theory and aspects of motor learning.

Method

Respondents

A total of 362 instrumental musicians took part in a questionnaire administered online via the platform SoSci Survey (www.soscisurvey.de). The quantitative data (analysed in Allingham &Wöllner, 2022) were screened for completeness, uniqueness, consistency, and quality. This resulted in a sample of 256 respondents who had filled out the questionnaire to a high standard (i.e. taking sufficient time, providing a range of rating responses, and providing consistent answers across different questions). Further details of the data screening can be found in Allingham & Wöllner (2022). In the current qualitative analysis we utilise this same sample of respondents ($N = 256$), based on the quantitative data screening.

Respondents were of 43 different nationalities, aged between 18 and 77 years ($M = 43.49$, $SD = 16.44$), and consisted of self-identified amateur musicians (113), professional performers (73), music teachers (32), music students (27), and "other professional musicians" (11). Respondents were from varying musical backgrounds (classical [182], pop/rock/blues [30], folk [27], and jazz [17]), and played various musical instruments (bowed strings [140], woodwind [37], keyboard [31], plucked strings [33], brass [9], percussion [5], and accordion [1]).

Materials and procedure

Five open-ended questions were analysed in the current study (Table 1). Respondents were also asked directly if they used slow practice with a yes/no response option. The 9 participants who responded "no" to this question were not asked subsequent questions about goals and techniques of slow practice (the first three items in Table 1). In addition, respondents reported basic demographic, and musical background information. The study was approved by the Ethics Committee of the Faculty of Humanities, University of Hamburg, and respondents consented to the anonymous use of their data for academic purposes only. No incentives for responding to the questionnaire were offered.

Table 1
Qualitative Questionnaire Items

Questionnaire item	Number of responses	Number of words
		Total, *M* (min, max)
Please give a short description of why you use slow practice (please give up to 4 reasons only).	247	6915, 27.99 (2, 159)
If you would like to give more information about your goals during slow practice, write it here.	72	2991, 39.97 (1, 296)
If you would like to comment further on how you use these (slow practice) techniques, please do so here.	67	5981, 52.48 (1, 188)
Do you think there are limitations of slow practice? What can slow practice NOT help you with? In what situations might slow practice NOT be helpful? (Please give up to 4 reasons only).	194	2878, 30.83 (1, 213)
Do you have any further comments on practice, slow practice, or this questionnaire in general?	75	3471, 39.88 (1, 281)

Analysis

We carried out thematic analysis using MAXQDA software, following the 6 step process described by Braun and Clarke (2006). The steps were: 1) familiarising with the data, 2) initial code generation, 3) searching for themes and initial thematic map generation, 4) revision of themes and re-definition of the thematic map, 5) defining and naming themes, and 6) writing the research report. Coding was inductive, in that codes were driven by the content of the data, but were also guided by the research questions (Joffe & Yardley, 2004), and included both manifest (i.e., explicit meaning of the text) and latent (i.e., implied meaning of the text) coding (Braun & Clarke, 2006). We also aimed to take contextual factors into account (i.e., genre, instrument, and expertise) during the coding process. Therefore, for each theme, we report descriptive, quantitative statistics for the expertise (years of reported music training) and musical genre (classical or non-classical) of participants whose responses contained the theme (Table 2). The purpose of this is to give context to the qualitative data.

The data consisted of 22,236 words in total with an average response length of 38.2 words (Table 1). The first author coded the data into 1509 segments, which were then categorised into 46 codes relating to perceived functions and limitations of slow practice, or methods of using slow practice (step two). These codes were then organised into thirteen themes. At this stage we wished to establish inter-coder agreement between the two authors in order to ensure that themes were clearly defined. To this end, the second author coded a 68-segment-subset of the total 1509 data segments into the thirteen themes, following a coding manual. Disagreements were resolved through discussion and the coding manual was subsequently refined (see Appendix). The resulting Cronbach's alpha measure of inter-coder agreement was > .73 for all themes, with a mean alpha of .85, indicating high agreement

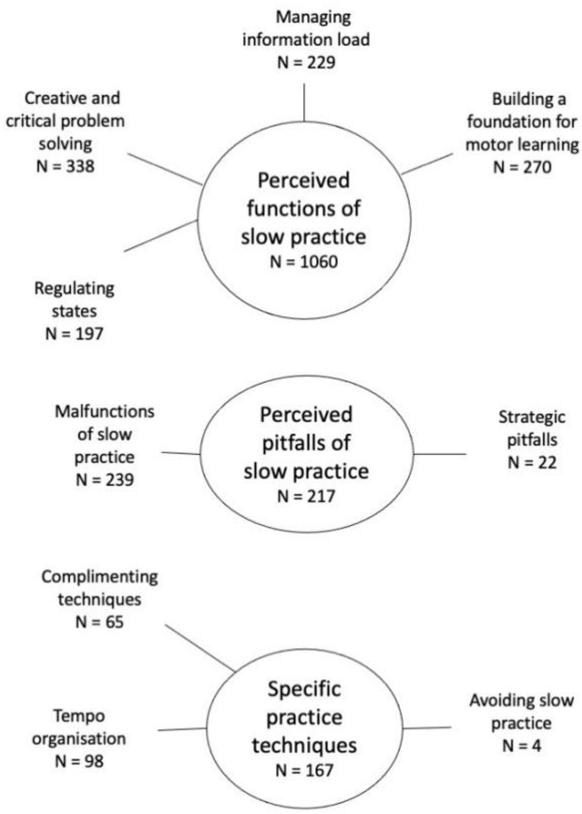
(Field et al., 2012). Subsequently, it became clear that some themes were not distinct from each other (for example, a theme called *using external resources* was not distinct from *complementing techniques*) and could be combined, resulting in nine final themes (Table 2, i.e., step four).

Table 2
Descriptive Statistics for Respondents Contributing to Each Theme

Theme	Musical Genre	Years of training
	Classical/non-classical	*M* (*SD*)
Managing information load	112/41	11.00 (7.74)
Regulating States	77/19	11.59 (6.35)
Building a foundation for motor learning	135/47	9.89 (7.79)
Creative and critical problem solving	129/49	10.57 (7.76)
Strategic pitfalls	19/3	11.36 (5.41)
Malfunctions of slow practice	106/46	10.22 (7.73)
Tempo organisation	74/24	12.13 (10.35)
Complementing techniques	48/17	9.42 (4.92)
Avoiding slow practice	1/3	10.50 (5.45)

The nine themes were categorised into three higher-level themes: Perceived functions of slow practice, Perceived pitfalls of slow practice, and Specific practice techniques (Figure 1). Regulating states was split into three subthemes of regulating Emotional, Mental, and Perceptual states, while Malfunctions of slow practice was split into two subthemes of Emotional-cognitive malfunctions, and Technical-practical malfunctions.

Figure 1. Thematic Map Displaying the Three Main Themes and Sub-themes



Results and discussion

Below we discuss the nine different themes, organised into the three higher-level themes (Figure 1). For each theme, the sub-thematic structure is displayed in a table along with data extracts as examples.

Perceived functions of slow practice

This overarching theme represents the majority of the data, encompassing information about how respondents viewed slow practice to be helpful, and their reasons for using slow practice. The four subthemes representing the perceived functions of slow practice were managing information load, regulating states, providing a foundation for motor learning, and creative and critical problem solving.

Managing information load. The reported use of slow practice to reduce or increase information load was the second most commonly perceived function of slow practice (Table 2). This theme highlights the role of cognitive load theory in explaining how slow practice may support learning. For some, slow practice was perceived as making playing easier, or was applied to difficult or complex material to make playing more accessible. For example, slow tempo was used to make “complex rhythms” or “challenging key signatures” (Table 3) more manageable. This implies a reduction of extrinsic CL through altering the manner (tempo) in which the task was carried out. Further, as musical material became “more familiar” (Table 3), the learner was able to quicken the tempo, implying that as information moved from working memory to long term memory, slow practice became less necessary. Respondents further reported using slow practice to avoid mistakes. They perceived errors to be harmful to learning (Table 3), or expressed fears that mistakes would become “chronic”, “habit”, or “programmed” into their playing. This supports the notion that slow practice is used to reduce extrinsic CL as a means of error avoidance. These perspectives are in line with theories of errorless learning which is said to support implicit learning processes (Wong & Lim, 2019), performance under pressure (Maxwell et al., 2001), and learner motivation (Pickard, 2021).

In addition, slow practice was viewed as enabling learners to process more details, or to focus on several musical elements as they played (Table 3). Others similarly reported that they were able to focus more deeply on accuracy while practising slowly, in line with previous findings that slow practice was used to achieve accuracy goals (Nielsen, 2001). This approach to learning appears to indicate an increase in germane CL, stimulating schema-construction in long-term memory. It appears then, that learners may adapt the effects of slow practice on CL to their individual needs.

Building a foundation for motor learning. This theme exemplifies using slow practice to build and refine motor skills, and was the most commonly mentioned function of slow practice. This theme was reported in terms of improving automaticity, familiarising with the music generally, laying technical foundations for developing fast playing, and developing motor skills such as coordination, fluency, and stamina (Table 4). Using slow practice to get familiar with new material is in line with previous qualitative findings (Chaffin et al., 2003). Further, respondents generally viewed slow practice as “essential”, “necessary” and “the only way” to build their skills and expand their repertoire. This highlights the foundational nature of slow practice. The development of automaticity through slow practice was seen as important for building fast playing skills, with some respondents believing “you can’t play something fast if you can’t play it slow” (teacher, classical, pianist). This exemplifies a use for slow practice early in learning, setting the basis for motoric memory which should later enable fast playing. The process of building motoric memory again implies construction of schemas, and therefore is consistent with the idea that slow practice can stimulate germane cognitive processes. This provides insight into how slow practice may support fast skills despite possible changes to motor organisation between slow and fast tempi (e.g., Dahl et al., 2011).

Table 3

Thematic Sub-structure for Managing Information Load

Subtheme level 1	Subtheme level 2	Example
Reducing extrinsic CL	Reducing difficulty	"Slowing the music down allows me to play difficult passages with complex rhythms or challenging key signatures. I then speed up once I am more familiar with the piece" (amateur, classical, violinist).
	Avoiding errors	"I never want to learn a mistake so I always practice slowly…. Playing at performance tempo before you are ready only makes the mistakes permanent" (professional, classical, violinist).
Stimulating germane CL	Detail/holistic focus	"I use slow practice in order to put everything under a microscope and observe what I am doing" (student, classical, violinist). "(I use slow practice) to improve the connection between intellect, emotion, and muscle memory" (professional, classical, violinist).
	Accuracy focus	"(I use slow practice) to make sure I'm actually hearing each note and each chord properly. To make sure I'm using the right technique so the piece doesn't fall apart when doing fast practice" (teacher, classical, pianist).

Regulating states. This theme captures use of slow practice to control aspects of emotional, perceptual, or mental states, and was the least commonly reported function of slow practice. In terms of emotion, respondents reported that slow practice gave them feelings of ease and control while playing (Table 5). It is possible that these emotions could be brought about by reduced extrinsic CL. Further, one respondent noted that practising "slowly and mindfully" (teacher, classical, clarinettist) boosted confidence when performing. Others noted that practising slowly promoted enjoyment and relaxation, in line with findings that slow movement is relaxing (Niksirat et al., 2017). Experiencing these positive emotional states during practice may support motivation to learn, and wellbeing (Lee et al., 2017).

Closely connected to these emotional themes, were reported changes to mental states involving concentration and mindfulness (Table 5). One respondent's description of effort optimisation, presence in the moment and experiencing "bliss" (Table 5), may refer to a state of flow. Indeed, conceptions of mindfulness and flow share overlapping characteristics, and are connected to aspects of focus and concentration (Lambert & Csikszentmihalyi, 2020). This suggests that slow practice might be able to encourage flow states by allowing the learner to optimise their skill/challenge balance through manipulation of extrinsic cognitive load. Other respondents similarly reported that slow practice allowed them to "pay attention", "concentrate", or "focus". As achieving focus in music practice has been described as essential to learning (Jørgensen & Hallam, 2011), this may be a valuable mechanism through which slow practice supports musical development.

Table 4

Thematic Sub-structure for Building a Foundation for Motor Learning

Subtheme level 1	Example
Automaticity	"I also use slow practice to build towards acquiring speed, because I can't play it fast until my fingers have memorised what they have to do" (teacher, classical, cellist).
Familiarising	"(I use slow practice) to learn the notes and get to know the rhythm and shape of the music" (amateur, classical, violinist)
Technical foundations	"It's the only way to cement technique" (amateur, classical, bassoonist).
Motor control	"For me, practising slowly has to do with muscle movement and technique" (amateur, pop/rock/blues, guitarist) "(I use slow practice) to hone coordination between right and left hands" (amateur, folk music, violinist).

Another sub-theme of changes to mental states was using slow practice to encourage conscious cognition (Table 5). Playing slowly was described as allowing the learner to avoid automatic motor processes and engage conscious cognition to solidify musical material in declarative memory (Table 5). This is similar to memorisation techniques described by Chaffin et al. (2009). Other comments described how slow practice enabled deep, deliberate practice, gave them time to think while playing, or allowed them to make conscious decisions about playing technique. One musician reported using slow practice to stimulate creativity when composing, writing that playing slowly helped to "avoid standard 'licks' and find something new" (amateur, pop/rock/blues, guitarist). This indicates use of slow practice to circumnavigate automatic motoric responses. Another respondent used slow practice to freshen their perspective on previously learned music, writing that even when music was learned well, practising slowly helped "to know better the music, to get a different feeling of it" (professional, pop/rock/blues, bassist). These perspectives are in line with the idea that slowness can be used to go beyond automaticity, to update schemas in long term memory, or to change musical interpretation.

The current reported increases in conscious cognition were viewed by respondents as beneficial to their creative practice. However, as bringing conscious attention to body movement has been found to impair motor performance (e.g., Allingham et al., 2021; Duke et al., 2011; Wulf, 2013), it would be an interesting topic for further research to explore whether such negative effects of attentional focus take place during slow practice. It is possible that the act of slowing down allows learners to avoid the performance degradation normally associated with increased conscious attention to movement. Further research on slow practice and attentional focus is needed to shed more light on this topic.

Respondents additionally reported that slow practice enabled regulation of their perceptual state. This was described in terms of developing new understanding of a musical phrase (Table 5), highlighting how changing tempo can alter perceived expressive musical content. It was also reported that playing slowly could change perceptions of intonation, allowing the learner to hear more precisely, or "perceive individual notes and evaluate their quality separate from their sequence" (amateur, classical, flautist). For some respondents, slow practice additionally heightened perception of movement, allowing them to develop "clearer sensation" and to notice "areas of unnecessary muscle tension" (professional, classical, cellist). This is in line with known uses of slowness to achieve heightened somatic awareness such as in the Feldenkrais method (Clark et al., 2015), and suggests that slow practice might play a role in improving instrument technique through awareness of inefficient muscle-use. These comments provide evidence that slow practice is sometimes used to find new ways of perceiving one's playing, in order to improve technique or find a new expressive intention.

Table 5

Thematic Sub-structure for Regulating States

Subtheme level 1	Subtheme level 2	Example
Emotional	Feelings of ease/ control	"(My goal during slow practice is) developing a feeling of ease and control, with focused expression, and bringing that feeling into performance tempo" (professional, classical, bass trombonist).
	Feelings of pleasure/relaxation	"Everything is simply easier and more enjoyable at a slower pace!!" (professional, classical, harpist).
Mental	Concentration/ mindfulness	"I'm trying to optimise my effort in order to be able to achieve the state of bliss, to be anchored in the present moment, kind of like meditation" (professional, classical, violinist).
	Conscious cognition	"Sometimes I use slow practising for memorisation, because you can't simply rely on muscle memory and have to actively engage with what you are playing" (student, classical, pianist).
Perceptual	-	"Playing the music slows (sic) allows me to hear the individual phrases and bring out the music within the music" (professional, folk music, bagpipe player).

Overall, the theme of regulating states indicated that instrumental musicians perceived slow practice as a useful way to regulate emotional, mental, and perceptual states to support learning. One respondent detailed how these three types of regulation may come together to create "a state of mind that is calm and in control and I really listen. It feels good and gets results fast" (teacher, classical, cellist).

Creative and critical problem solving. This theme encompassed use of slow practice to solve both technical and expressive-interpretative problems, requiring critical self-assessment (Table 6). The types of problem-solving reported included complex issues such as making decisions about bowing styles and fingering patterns, implying careful thought and experimentation. Working on more basic musical components such as intonation, rhythm, and sound quality was also reported. Slowness may help this kind of work by reducing extrinsic CL and giving the learner more capacity for conscious thinking. Identifying problems during slow practice was also highlighted, indicating that slowness may help to uncover problems not apparent at faster speeds. This is reminiscent of descriptions of slow practice as a magnifying glass, allowing the learner to assess their playing in greater detail. In a similar manner, slow practice appeared to help learners develop understanding of the musical material and the techniques required. Improved musical understanding was seen as supporting interpretations, allowing the performer to “translate (the music) into a story” (professional, classical, violinist). Improved technical understanding was viewed as contributing to “proper, healthy, sustainable technique” (amateur, classical, cellist). Finally, respondents reported using creative and critical slow practice to achieve expressive-interpretative goals, such as experimenting with different expressive ideas. Extra time afforded by slow playing may help the learner to make performance decisions, while changing the tempo might allow the music to be seen in a new light. The slow, analytical work described in this theme is similar to the slow practice described by Chaffin et al., (2003) for solving problems and getting to know the music. This approach to slow practice further indicates that slow practice is not only about reducing extrinsic CL to make work easier, but also may support intense and concentrated practising.

Table 6

Thematic Sub-structure for Creative and Critical Problem Solving

Subtheme level 1	Subtheme level 2	Example
Technical problems	Problem solving	“(my slow practice) includes making conscious decisions about where to place the bow on the string and in the frog/middle/tip and the melding of fingers with the bow to ease technical challenges within the musical phrase” (professional, classical cellist).
	Problem identification	“(slow practice) brings out places I am not comfortable” (amateur, classical, pianist).
Developing understanding	Musical material	“I use slow practice to unpick and understand harmonic structure” (teacher, classical, saxophonist).
	Technique	“(I use slow practice) to break down and analyse the motion of each arm/hand/finger” (professional, classical, violist).
Developing expression/ Interpretation	-	“(I use slow practice to) decide on how it feels to play it and where I should put emphasis” (professional, folk music, violinist)

Perceived pitfalls of slow practice

This overarching theme describes ways in which slow practice was seen as counterproductive or suboptimal (malfunctions of slow practice), and specific practice strategies that were seen as unhelpful (strategic pitfalls). A smaller number of respondents contributed to these themes (Table 2), but these data nonetheless provide insight into potential difficulties with practising slowly.

Malfunctions of slow practice. The perceived ways in which slow practice could malfunction were categorised as either technical-practical, or emotional-cognitive (Table 7). The first technical-practical malfunction was the way in which slow practice could alter the technical requirements of the music. This was perceived as inefficient. For example, string players reported that certain bow techniques would not work at slow speeds, and that left-hand technique would change depending on the tempo. Woodwind and brass players wrote that playing too slowly could make breath control unnecessarily difficult. Others noted that fast practice would eventually be required in order to learn fast playing technique, and that slow practice "doesn't give you the speed and dexterity required" (amateur, pop/rock/blues, bassist). These views support motor skills research which has shown that slow movement sometimes creates extra difficulty (Van Der Wel et al., 2009), and that motor system organisation can change depending on the speed of action execution (Dahl et al., 2011; Goebl & Palmer, 2008; Winold et al., 1994). Due to these changes in instrument technique, some respondents noted that they could not realise their expressive intentions at slow tempi. Four musicians (3 jazz, 1 classical) noted that the intended tempo was essential for capturing the "swing" or "groove" of a piece. To these respondents, practising slowly removed the music from its original context, making it difficult to express the music authentically. Changing musical context through tempo alteration is the same mechanism previously discussed as allowing learners to gain new perspectives. However, this mechanism is viewed here as unhelpful in determining final performance expressions. The utility of this aspect of slow practice may thus depend on the perspective of the learner.

The second sub-theme of malfunctions of slow practice encompassed potential negative impacts of slow practice on an emotional-cognitive level. One problem was the possibility of "getting stuck" in slow tempo, or a slow way of thinking. For example, a folk guitar teacher felt that students who always practice slowly may come to believe that they should always avoid mistakes (Table 7). This would mean that they are unable to progress to faster tempi, hence they become "stuck" at slow tempi. This perspective is reflected in pedagogical ideas promoting the utility of making mistakes while practising (Kruse-Weber & Parncutt, 2014). In this view, the slow errorless learning previously discussed is seen as lacking in learning opportunities, creating over-cautious students. Others expressed similar sentiments, highlighting the need to learn how to "control your mind in a fast tempo" (professional, classical, pianist). This indicates differing cognitive skills necessary for slow and fast playing. Similarly, some respondents felt that slow practice would not adequately support performance skills, as they required expansion of their comfort zone into fast playing in order to feel confident.

Lastly, some respondents experienced negative emotions during slow practice, reporting becoming bored, impatient, or losing concentration. This highlights individual differences in optimal practising styles. While some may find slow practice focusing and relaxing, others may feel the need to play fast in order to feel inspired. This is in line with previous findings that factors such as gender, expertise, musical genre, or musical instrument played may influence aspects of music practice (Hallam et al., 2012, 2017, 2020).

Strategic pitfalls. We identified two main strategic pitfalls of slow practice described by respondents: practising too slowly, and only using slow practice (Table 7). When reporting practice that was too slow, respondents referred to previously discussed malfunctions of slow practice. For example, when practising too slow "breathing becomes impossible" (amateur, classical, bassoonist), indicating an impractical change to instrument technique (in line with Van Der Wel et al., 2009). Another concern was that slow practice "would take away the musical expression" (amateur, classical, bassoonist), implying that the music had been removed from its authentic context. Concerns about practice being "too easy" (Table 7), may refer to the importance of finding an optimal skill/challenge balance, previously discussed in terms of flow and cultivating positive emotional states (Csikszentmihalyi, 1990). Further could explore if there exists a general rule for finding the optimal practice tempo to support learning. The second strategic pitfall was using only slow practice, described as the need for a balance of slow and fast work (Table 7). Others similarly described how slow practice was “only part of a toolbox of techniques” (amateur, classical, cellist). Indeed, it seems likely that many of the perceived malfunctions of slow practice could be avoided by inclusion of both slow and fast playing.

Table 7

Thematic Sub-structure for Malfunctions of Slow Practice and Strategic Pitfalls

Subtheme level 1	Subtheme level 2	Example
Malfunctions of slow practice		
Technical-practical malfunctions	Altering technique	“Often slow practice changes technique – this is undesirable as it means I’m learning to play a phrase in two (or more) ways” (teacher, classical, pianist).
	Altering expression	“I find it difficult to play correct articulations, dynamics, phrasing, or other factors that express emotional content at a slow tempo…. Partially because they sound wrong and out of context” (amateur, pop/rock/blues, guitarist).
Emotional-cognitive malfunctions	Getting stuck	“Students get stuck at slow tempos. Slow practice can be conflated with never making mistakes. Making then correcting mistakes is possibly more important than slow practice” (teacher, folk music, guitarist).
	Lack of performance skills	“It is necessary to practice at full speed to overcome any nerves by reassuring yourself you are capable of performing at speed” (amateur, classical, violinist).
	Negative emotions	“(a limitation of slow practice is) Boredom! Do it too much and you will skip practice because it’s so boring” (amateur, classical, bassoonist).
Strategic Pitfalls		
Practising too slowly	-	“Practice must be slow enough to allow learning but not so slow as to be too easy” (professional, classical, cellist).
Only using slow practice	-	“You can’t expect to run fast in a race if you’ve only practiced at walking speed. . .The body needs to warm up and train progressively in order to complete difficult tasks” (professional, classical, harpist).

Specific practice techniques

This theme encompassed descriptions of practice techniques, either utilising slow practice or as alternatives to slow practice. While the previous themes covered views about how slow practice affected learning, this theme encompassed more detailed descriptions of how practice was carried out.

Specific practice techniques mentioned were categorised into three sub-themes: tempo organisation, complementing techniques, and avoiding slow practice. Within tempo organisation, respondents reported using gradually increasing tempo, alternating between slow tempo and final performance tempo, and practising at randomly ordered tempi (random tempi use was only mentioned by one respondent). They also reported using slow practice mostly in the early learning stages (46 respondents), sometimes in later stages (7 respondents), and that the nature of slow practice changed depending on the stage of learning (3 respondents).

The gradually increasing tempo approach was sometimes combined with a back and forth between tempi (Table 8). One respondent described using small increases in tempo as stepping stones, moving between faster and slower speeds as needed; perhaps to consolidate learning, regulate states in the moment, or resolve problems as they arose. Similarly, gradually increasing tempo was sometimes combined with alternating between slow and fast. For example, “increasing the metronome speed when I correctly execute the passage” but returning to a fast tempo in between each iteration of the slower tempo (teacher, classical, double bassist). A possible benefit of this approach could be using the fast tempo to assess progress and identify problems. Indeed, the alternating tempi approach was described this way, with the fast tempo allowing the learner to “measure my progress” and the slow tempo giving “time to resolve my mistakes” (amateur, pop/rock/blues, guitarist). This exemplifies how systematic use of tempo organisation in practice may allow the learner to transition from slow to fast playing, with fast practice providing a self-assessment tool (cf. Byo & Cassidy, 2008).

Alternating between slow and fast tempi was also described as important in illuminating biomechanical and technical changes relating to tempo. One respondent felt that incorporating fast playing into slow practice was “wise”, as “we do sometimes use our muscles differently at speed” (professional, classical, cellist). This depicts a solution to the problem of getting stuck in slow playing, through incorporating fast tempi into slow practice.

Offering solutions to the pitfall of only using slow practice, respondents described other techniques they used alongside slow practice. A particularly interesting technique was that of practising backwards (Table 8). This response illustrates an intuitive approach to connecting slow practice to faster playing. Similarly, respondents also reported using rhythm variation and chunking. These methods may address issues of becoming stuck in slow tempi by encouraging fast motor organisation skills, while managing cognitive load difficulties by inserting pauses into the music. Further methods reported were playing with flexible tempo (adjusting speed of playing to the learners skill level), playing faster than required so that the performance tempo would feel easier, (supporting performance confidence and positive emotions), and using external resources to support practice such as using a metronome, recording device, or taking advice from others. These approaches illustrate how slow practice in combination with additional techniques can allow learners to harness the benefits of slow practice while avoiding the possible pitfalls.

Finally, a handful of respondents (*N* = 4) reported adopting the strategy of limiting or avoiding slow practice completely (Table 8). One respondent displayed strong negative opinions about slow practice, describing it as "detrimental to music learning" (professional, folk music, guitarist). This perspective on slow practice was rare in the current study. Nonetheless, it is useful to note that some musicians actively dislike and avoid slow practice. Further research could explore which individual factors may affect opinions on slow practice, such as musical genre, skill-level, instrument played, or personality factors, and what kinds of musical goals might be achieved without slow practice.

Table 8

Thematic Sub-structure for Specific Practice Techniques

Subtheme level 1	Example
Tempo organisation	"If the music is very fast it also helps to practice playing it at increasing tempii (sic) to train my fingers. I would usually vary the tempii (sic) – up a bit, down a little, up a bit more, down a little etc." (amateur, classical, bassoonist).
Complementing techniques	"I rate practising backwards, and I teach my pupils to do it too. So we practice the last bar, slowly; then the last 2 bars; then the last 3 bars etc. We find ourselves naturally speeding up as we reach the "practiced" last bars, so that getting up to speed happens naturally. Also, each run is satisfying, as you finish on the bit you can play" (professional, pianist, rock/pop/blues).
Avoiding slow practice	"I don't persist with slow practice…. I'll much more readily give up on slow practice and spend time finding other strategies" (teacher, classical, saxophonist).

Summary and conclusions

This study set out to investigate instrumental musicians' perceptions of the benefits and limitations of slow music practice, and specific techniques of slow practice. Through thematic analysis of responses to open-ended questions about slow practice, we have described several possible functions of slow practice in supporting music learning, as well as malfunctions of slow practice that might hinder learning, from diverse musician perspectives. In addition, we highlighted perceived strategic pitfalls of using slow practice and details of specific slow practice techniques viewed as beneficial to learning. On the whole, the current findings show that slow practice was seen as a largely useful, sometimes essential practice method, especially when balanced with alternative approaches.

We proposed four possible uses of slow practice as managing information load; regulating emotional, mental, and perceptual states; providing a foundation for motor learning; and supporting creative and critical problem solving. We further suggest that these uses of slow practice function through the reduction of extrinsic cognitive load (CL) and the stimulation of germane CL (Owens & Sweller, 2008). The current findings indicate that slow practice may allow learners to optimise the balance of skill to challenge in their playing, (an important ingredient of achieving flow states, Csikszentmihalyi, 1990); regulate emotional, mental, and perceptual states during practice; and support construction of schemas in long term memory (in line with CLT, Owens & Sweller, 2008). Supporting findings of Chaffin et al., (2009; 2003), our results also suggest that slow practice can promote conscious thinking for problem solving and creative work. Further research should aim to verify these proposed functions of slow practice through behavioural measures. For example, experimental research could explore changes in CL during practice utilising behavioural measures such as dual-task paradigms (Maes et al., 2014). We further found that learners viewed slow practice as supporting their ability to regulate their states of concentration and mindfulness. This suggests that further research into how slowness in music practice might encourage flow experiences would be useful. As flow may support motivation to learn and general wellbeing (Bakker, 2005; Lee et al., 2017; Spahn et al., 2021), this topic should be of interest to music educators.

We additionally reported possible malfunctions of slow practice, such as removing the musical material too far from its technical and expressive context, eliciting negative emotions, getting stuck in slow ways of playing, and failing to teach performance skills. These malfunctions may come about as a result of strategic pitfalls of the learner or teacher such as choosing a practice tempo that is too slow, and using only slow practice. Finally, we reported specific practice techniques described by respondents, providing insight into how musicians may bridge slow practice with fast playing. For example, utilising creative tempo organisation approaches, and balancing slow practice with other methods. This theme provided insight into how difficulties of biomechanical organisation in different tempi may be overcome in music practice.

As the current research utilised self-report data only, further research is needed to establish if the uses of slow practice reported here are observed in real practice behaviour, as well as how individual differences may systematically affect practice strategies. For example, future work may investigate how benefits of slow practice may differ depending on instrument played, personality of the learner, and stage of learning. The current sample of musicians was diverse, allowing us to observe perspectives from different musical backgrounds. However, there was a greater number of classical musicians compared to other genres, and more string players than other instruments. This means that answers may be biased towards the background of classical string-players. Indeed, our study points to the role of individual differences in optimal music practice, in line with previous findings that practice may depend on factors such as musical genre, instrument played, and expertise (Hallam et al., 2012, 2017, 2020). We found that the particular functions of slow practice might be determined by the learner's approach and the physical constraints of the instrument. Where some musicians see benefits to slow practice, others might see limitations. The current findings can inform further research on musical and motor skill acquisition in exploring aspects of slowness and temporality in learning, and may inspire music educators to consider precise reasons for, and specific methods of employing slow practice in teaching.

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Appendix

Refined coding manual

Theme	Sub-theme	Description	Example codes
Perceived functions of slow practice			
	Managing information load	Indicates that slow practice is used to somehow manage the information load of the musical material. This could be to reduce load (i.e., make it easier, give more time), or to increase load (i.e., to take in more details). Includes using slow practice for difficult material, and to work on accuracy, perfection, or clarity, which implies reduction of information load.	Slow practice increases time for information processing/ makes practising easier. Slow practice is used for: difficult/complex material, to avoid errors, for accuracy/perfection/clarity, to process more details, to achieve holistic focus (focus on several things at once).
	Building a foundation for motor learning	Slow practice is used as a starting point for difficult motor skills, and is seen as providing necessary groundwork on which more difficult skills are built. This theme encompasses slow practice being used to develop motor skills generally, and fast playing. Also, slow practice being seen as essential, necessary, or the only way to enhance motor skills.	Using slow practice to build muscle memory/automaticity/ consistency, to support fast playing/fluency or learn fast passages, to develop dexterity, stamina, coordination between hands, using slow practice as a foundation for further practice such as to learn the notes, get to know the music, get a feel for the piece, familiarise with the musical material, stating that slow practice is the only way for motor skills improvement.

	Regulating states	Slow practice is used to regulate emotional, mental or perceptual states. This could mean doing slow practice because it is enjoyable, or builds confidence (emotional), because it helps concentration/focus, or achieves a meditative state (mental), or because it changes perception or perspective (perceptual, e.g., slow practice helps the learner to hear better, or to gain a new perspective on the music). Also includes using slow practice to be able to think consciously about playing and to avoid automatic pilot.	Emotional: building confidence, feeling comfortable, feelings of ease, for pleasure/relaxation/calm. Mental: supporting concentration/awareness/mindfulness, supporting conscious thinking, avoiding automaticity. Perceptual: changing perception/perspective, supporting listening, allowing somatic awareness/ muscle relaxation/ efficiency of muscle use.
	Creative and critical problem solving	Slow practice is used to creatively solve problems and critique/ assess own playing. Problems may be technical, expressive, interpretative etc. Includes specific practice goals such as working on sound, intonation or timing.	Using slow practice to: identify/ solve problems, self-evaluate, develop expressive/interpretative, improvisational skills, support expressivity through technique, understand the music, analyse the music/ structure, understand in general, understand technique better, work on specific goals such as intonation/ sound/ rhythm/ timing.
Perceived pitfalls of slow practice			
	Malfunctions of slow practice	Describes specific ways in which slow practice may be harmful to playing, or a sub-optimal practice method. Also describes functions of fast practice, as this implies an opposite to slow practice - i.e., certain skills require fast practice.	Losing clear goals/ concentration, becoming bored/ impatient/ tired, slow practice does not improve confidence or performance skills, slow practice alters technique, practising fast movement is needed too, some techniques are not easier slow, expression can get lost in slow practice, groove/ swing feel can be lost or changed, can lose sight of the bigger picture/ get bogged down in details, fast practice is needed to learn fast thinking.
	Strategic pitfalls	Describes flawed ways of using slow practice which could lead to sub-optimal practice or even harm the learner's playing.	Practising too slowly, using only slow practice - i.e., slow practice should

			be combined with other methods of practice.
Specific practice techniques			
	Tempo organisation	Describes a method of tempo organisation while practising, or the stage of learning in which slow practice is used.	Using gradually increasing tempo, alternating between slow and fast tempo, using random tempi, using slow practice in the early/ late stage of learning, the nature of slow practice changes depending on the stage in which it is used.
	Complementing techniques	Describes specific practice techniques/ strategies other than slow practice.	Chunking, rhythm variation, backwards practice, practising faster than needed, playing with flexible tempo or meter.
	Avoiding slow practice	Describes deliberately not using slow practice or limiting its use as much as possible.	Never using slow practice, wary of using slow practice, limiting use of slow practice.

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Page 01

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Tempo and Slowness in Instrumental Music Practice

Welcome to this questionnaire study on instrumental music practice. The purpose of this study is to explore the psychological mechanisms of music practice - in particular, how varying or slowing tempo helps music learning. Practising music slowly is a very common, intuitive technique, but we know very little about the psychology of how learning takes place this way. By taking part, you will be contributing to scientific music psychology research, which will inform music education, performance practice, and psychological theory. We will ask you some questions about your general background and about the way that you practice music. The questionnaire should take about 20 minutes to complete. To take part you must be over 18 years old, and play a musical instrument. People of all levels and abilities are welcome to take part, from beginners to professionals.

By clicking *next* you agree that we may use the data you provide for the purposes of this study. Your data will be stored anonymously and securely, and will not be shared with any third parties. It will not be possible to identify you from your questionnaire answers. If you decide to quit the questionnaire at any time, you may do so without any repercussions.

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If you would like to get in touch about this study you can do so at emma.allingham@uni-hamburg.de

Click next to continue.

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Before we begin, let's define some concepts so that we are clear on the questions we are asking.

This study is about **instrumental music practice.** That does not include singing practice. Please answer the questions only about practising an instrument.

We are interested in **practice** that takes place **alone**, not in groups. Please, answer the questions only about practice that you do alone, not ensemble or duo rehearsals.

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Let's begin.

1. Which musical instrument do you play?

You must play an instrument other than voice to take part. If you play more than one, choose the one for which you spend or have spent the most time practising. The rest of the questions should be answered about the instrument you choose here.

2. Do you play any other musical instruments or sing?

If so, write the details here.

3. Which musical genre do you mostly play?

Please choose only one. Choose the one you mostly play and/or mostly identify with. (e.g classical, jazz, folk, pop)

4. Do you have significant experience in any other musical genres?

If you like, you can write them here.

5. At the peak of your music practising, how many hours do/did you practise per day, on average?

If you’re not sure, an estimate is fine.

hours per day

6. In the last year, how many music performances have you given on the instrument you specified earlier?

If you’re not sure, an estimate is fine. Auditions and exams count as performances, as well as public concerts or gigs.

performances

7. At what age did you start learning your instrument?

years old

8. For how many years did you receive lessons on your main instrument?

If you are self-taught enter 0

[ ] years

9. Which of the following most applies to you:

I am a:

- ◯ music student
- ◯ music teacher
- ◯ amateur musician (you play music as a hobby)
- ◯ professional musician (performer)
- ◯ other type of professional musician (e.g. composer, producer)

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10. Is your main area of study performance of a musical instrument?

- ◯ yes
- ◯ no

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11. This question is about your approach to learning a new piece.

Select the answer which most applies to you.

When I start learning a new piece, I first work on:

- ◯ technical aspects.
- ◯ expressive aspects.
- ◯ both technical and expressive at the same time.

12. This question is about your general practice habits.

Please rate each statement from *Almost none* to *Almost All*.

How much practice time, in general, do you spend:	*Almost none* 1	2	3	4	5	6	*Almost all* 7
working on technical skills	◯	◯	◯	◯	◯	◯	◯
working on expressive skills	◯	◯	◯	◯	◯	◯	◯
working with defined goals (i.e deliberate practice)	◯	◯	◯	◯	◯	◯	◯
working without defined goals (i.e non-deliberate practice)	◯	◯	◯	◯	◯	◯	◯

13. This question is about your confidence in different musical skills. Please rate how confident you are in each of the skills below.

Please rate each item from *Not confident at all* to *Very confident*.

	Not confident at all 1	2	3	4	5	6	*Very confident* 7
Performing music under pressure (i.e a performance situation in which the outcome is important to you).	◯	◯	◯	◯	◯	◯	◯
Performing music from memory.	◯	◯	◯	◯	◯	◯	◯
Sight-reading music.	◯	◯	◯	◯	◯	◯	◯
Solving a problem in your music practice without help from someone else.	◯	◯	◯	◯	◯	◯	◯
Musical improvisation.	◯	◯	◯	◯	◯	◯	◯

14. Now, a few questions about your music practice in general.

Please rate each statement from *Not at all* to *Always*.

When practising or learning music, how often do you:	*Not at all* 1	2	3	4	5	6	*Always* 7
Evaluate the quality or progress of learning.	◯	◯	◯	◯	◯	◯	◯
Rearrange materials to improve learning (changing the order of passages within a piece or the inclusion of studies or other related musical material).	◯	◯	◯	◯	◯	◯	◯
Set goals and plan for the sequencing, timing, and completion of activities in relation to those goals.	◯	◯	◯	◯	◯	◯	◯
Seek information from non-social sources (recordings, concerts, books or scores).	◯	◯	◯	◯	◯	◯	◯
Keep records of events or results.	◯	◯	◯	◯	◯	◯	◯
Select and rearrange the physical setting (practice environment) to facilitate learning.	◯	◯	◯	◯	◯	◯	◯
Arrange or imagine a reward/punishment for success/failure.	◯	◯	◯	◯	◯	◯	◯
Rehearse and make an effort to memorise through practice.	◯	◯	◯	◯	◯	◯	◯
Seek assistance from peers, teachers or others.	◯	◯	◯	◯	◯	◯	◯
Review records of past performances or exams, notes or texts.	◯	◯	◯	◯	◯	◯	◯

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Flow

15. In your own personal practice, do you use *slow practice*?

In this case, *slow practice* means practising music at a tempo slower than the desired performance tempo.

◯ Yes

◯ No

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16. Please give a short description of why you use slow practice.

Please give up to 4 reasons only.

17. Think of a time recently when you practised slowly. Imagine the slow practice as vividly as you can. Rate your agreement with the following statements about that practice session, as you remember it.

Please rate each statement from *Not at all* to *Very much*.

	Not at all 1	2	3	4	5	6	*Very much* 7
I feel just the right amount of challenge.	○	○	○	○	○	○	○
My thoughts/activities run fluidly and smoothly.	○	○	○	○	○	○	○
I don’t notice time passing.	○	○	○	○	○	○	○
I have no difficulty concentrating.	○	○	○	○	○	○	○
My mind is completely clear.	○	○	○	○	○	○	○
I am totally absorbed in what I am doing.	○	○	○	○	○	○	○
The right thoughts/movements occur of their own accord.	○	○	○	○	○	○	○
I know what I have to do each step of the way.	○	○	○	○	○	○	○
I feel that I have everything under control.	○	○	○	○	○	○	○
I am completely lost in thought.	○	○	○	○	○	○	○
Something important to me is at stake here. [i.e something important is at risk]	○	○	○	○	○	○	○
I won’t make any mistakes here.	○	○	○	○	○	○	○
I am worried about failing.	○	○	○	○	○	○	○

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18. This question is about the specific goals you have when you practise slowly. Rate each item with how often you have this goal during *slow practice*. It is possible to have more than one goal at a time.

Please rate each statement from *Almost never* to *Almost always*.

During slow practice, my goal is:	*Almost never* 1	2	3	4	5	6	*Almost always* 7
to work on rhythm.	◯	◯	◯	◯	◯	◯	◯
to work on correct notes or intonation.	◯	◯	◯	◯	◯	◯	◯
to work on dynamics.	◯	◯	◯	◯	◯	◯	◯
to work on articulation.	◯	◯	◯	◯	◯	◯	◯
to work on understanding or expressing musical structure.	◯	◯	◯	◯	◯	◯	◯
to work on technique.	◯	◯	◯	◯	◯	◯	◯
to work on expression.	◯	◯	◯	◯	◯	◯	◯
to warm up my muscles.	◯	◯	◯	◯	◯	◯	◯
to calm my nerves before a performance.	◯	◯	◯	◯	◯	◯	◯
to develop my memorisation skills.	◯	◯	◯	◯	◯	◯	◯
to concentrate on how my movements feel.	◯	◯	◯	◯	◯	◯	◯
to concentrate on how the music sounds.	◯	◯	◯	◯	◯	◯	◯
to concentrate on the emotions in the music.	◯	◯	◯	◯	◯	◯	◯

19. If you would like to give more information about your goals during slow practice, write it here.

20. This section is about specific practice techniques related to tempo. For each practice technique, rate how often you use this technique in your personal practice.

Please rate each item from *Almost never* to *A lot*

	Almost never 1	2	3	4	5	6	*A lot* 7
Practising at a tempo slower than the performance tempo.	◯	◯	◯	◯	◯	◯	◯
Starting at a slow tempo and gradually increasing.	◯	◯	◯	◯	◯	◯	◯
Alternating between the performance tempo and a slower one.	◯	◯	◯	◯	◯	◯	◯
Playing at various tempi in a random order.	◯	◯	◯	◯	◯	◯	◯
Playing at the performance tempo, breaking the music into small chunks.	◯	◯	◯	◯	◯	◯	◯
Practising a section in a variety of different rhythms.	◯	◯	◯	◯	◯	◯	◯

21. If you would like to comment further on how you use these techniques please do so here.

For example, maybe you use certain techniques at the beginning of learning a piece, and others nearer performance time.

22. This question is about how difficult it is to return to the original performance tempo after practising at a slower tempo.

Please rate the question below from *Not difficult at all* to *Very difficult*

	Not difficult at all						*Very difficult*
How difficult is it returning to the performance tempo after practising slowly?	◯	◯	◯	◯	◯	◯	◯

23. Please give a short description of why you do or do not find it diffucult returning to the performance tempo.

Please give up to 4 reasons only.

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24. In your own personal practice, do you use mental practice?

Mental practice is practising without your instrument, imagining that you are playing. This could be practising with or without the musical score. It must be deliberate practice, with specific goals, and concentrating on the task.

◯ Yes
◯ No

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25. This question is about your use of tempo in mental practice.

Please rate each statement from *Almost never* to *Almost always*.

When I practice mentally:	1 *Almost never*	2	3	4	5	6	7 *Almost always*
I imagine the music at the performance tempo	◯	◯	◯	◯	◯	◯	◯
I switch between imagining the music at a slow tempo and at the performance tempo	◯	◯	◯	◯	◯	◯	◯
I imagine the music at a range of tempi	◯	◯	◯	◯	◯	◯	◯

26. If you would like to give more information about how you use tempo in mental practice, write it here.

27. Do you think there are limitations of slow practice? I.e. What can slow practice NOT help you with? In what situations might slow practice NOT be helpful?

Please give up to 4 reasons only.

28. Do you have any further comments on practice, slow practice or this questionnaire in general?

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Finally, some details about you.

29. What is your sex?

- ◯ female
- ◯ male
- ◯ other

30. What is your nationality?

[ ]

31. In which country are you currently living?

Country: [ ]

32. How old are you?

I am [ ] years old

Last Page

You have completed the survey. Thank you for taking part!

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