Testing a Metacognitive Account of the Attentional Focus Effect in Music Performance

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Abstract

Focusing on external movement outcomes rather than the movements themselves has been reported to enhance motor performance, although the mechanisms for this attentional focus effect remain unclear. We examined whether the effectiveness of an attentional focus depends on the precision of metacognitive representations of the attended movement aspect. Amateur guitarists (*N* = 65, 52 valid metacognitive estimates) played a melody under internal, external and no-focus instructions. We assessed pitch and rhythm accuracy and estimated participants' ability to monitor two movement aspects corresponding to the attentional foci: internal/visual (finger positions) and external/tonal (pitch outcomes). Against our expectations, and challenging dominant accounts, focusing externally did not improve musical performance, nor was it moderated by metacognitive ability. Exploratory analyses revealed no interaction with expertise. Interestingly, participants demonstrated greater metacognitive precision for internal/visual information than external/tonal.

Keywords

metacognition, motor performance, focus of attention, music performance

Introduction

Consider the penalty kick deciding the championship, a surgeon's scalpel approaching a vital organ, or a pianist's fingers over the keys for the opening notes of a concerto. In these moments, the aspect to which one directs one's attention may determine the success or failure of the intended movement. The Focus of Attention (FOA) effect — a difference in motor performance depending on whether attention is focused internally (on one's own movements) or externally (on the effects of those movements) — has been the subject of extensive research (McNevin et al., 2003; Wulf, 2013). Seven meta-analyses have documented an advantage of external focus over internal focus. While five of these examined specific tasks, including balance (Kim et al., 2017), sprinting (Li et al., 2022), jumping (Makaruk et al., 2020), strength (Grgic et al., 2021) and endurance (Grgic & Mikulic, 2022), two meta-analyses have also demonstrated the benefit across a wider range of motor tasks (Chua et al., 2021; Nicklas et al., 2022). The FOA phenomenon has been suggested to arise because directing attention externally promotes automatic control processes, thereby improving performance. In contrast, focusing internally increases self-focus and conscious control, disrupting automaticity and making movements less smooth and more error-prone (Bell & Hardy, 2009; McNevin et al., 2003; Wulf, McNevin, et al., 2001; Wulf, Shea, et al., 2001; Wulf & Lewthwaite, 2016).

Beyond the effects observed, proposed explanations of the FOA effect often lack specificity regarding the different neural and computational mechanisms involved in motor planning and execution under different attentional foci (Collins et al., 2016; Ehrlenspiel, 2001; Kuhn & Taube, 2025; Maurer & Zentgraf, 2007; Peh et al., 2011). Additionally, broad claims about the general benefits of an external focus (Bell & Hardy, 2009; Chua et al., 2021; Wulf et al., 2002) tend to overlook sources of variability, such as skill level (Pacherie & Mylopoulos, 2021; Perkins-Ceccato et al., 2003) and task complexity (Maurer & Munzert, 2013), leading to current critiques that these effects may be overstated in the literature or may strongly reflect publication biases (McKay et al., 2024). Without clarifying FOA mechanisms, attempts to generalize it across different performance and learning settings risk being ineffective or even misleading.

We propose and test a possible account of how attentional focus may influence performance: the precision of metacognitive representations. Specifically, we ask whether the effectiveness of a given focus depends on how precisely individuals can monitor the movement information — either internal or external — they are asked to attend. Because monitoring precision varies across individuals, we expect corresponding differences in performance: a person that can monitor the outcomes of their own movements precisely will perform better under an external focus (relative to baseline), whereas a person with low monitoring precision may show little or no such advantage. Conversely, individuals who can accurately monitor the movements themselves are expected to perform better under an internal focus, compared with those with lower monitoring precision.

Recent studies suggest that individuals can report details about their voluntary movements above chance level, with varying efficiency across participants (Sinanaj et al., 2015) and tasks (Charles et al., 2020; Locke et al., 2020; Pereira et al., 2023). In one study, participants moving a manipulandum to throw a virtual ball were able to monitor both proximal (i.e., arm position) and distal (i.e., ball trajectory) movement representations (Arbuzova et al., 2021). This proximal-distal distinction aligns with the internal-external FOA dichotomy: proximal monitoring emphasizes bodily mechanics (internal focus), whereas distal monitoring emphasizes outcomes (external focus).

These two types of monitoring provide an opportunity to isolate potential cognitive components of the attentional focus effect and understand its potential mechanisms. Monitoring processes enable the formation of metacognitive representations, which not only reflect basic information about the world, but also incorporate information about the reliability or utility of that information. Accurately assessing the reliability of perceptual information can support more efficient behavioral control (Shea et al., 2014). Hence, we propose that an individual's ability to access and use metacognitive representations may determine how effectively they can control behavior under different FOA conditions: proximal monitoring ability may support benefits of an internal focus, while distal monitoring may support benefits of an external focus.

To test this idea, we turn to a domain that involves complex, high-precision movements: music performance. Like sports, music involves skilled movement, meaningful variation in skill level, and measurable performance outcomes that require monitoring of both bodily movement (e.g., finger position, hand posture) and its effects (e.g., quality of sound). However, unlike sports, music relies on a unique form of task complexity (fine motor control) and a different type of sensory feedback (sound). These features allow us to deepen our understanding of FOA by investigating how metacognitive ability may shape its effects across domains and task types.

In this study, we first assessed the FOA effect in guitar playing and then examined how it interacts with metacognitive access to movement parameters, using a decision-confidence task to quantify metacognitive ability (Fleming & Lau, 2014). Based on findings in sports research, we hypothesized that (1) musical performance will improve with an external focus of attention compared to an internal focus. We also expected the benefits to depend on metacognitive ability.

Specifically, we hypothesized that (2.1) monitoring proximal (internal) aspects of movement would modulate musical performance in an internal focus of attention condition and that (2.2) monitoring distal (external) aspects of movement would modulate performance in an external focus of attention condition (**Fig. 1a**).

Research Transparency Statement

General Disclosures

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Study Disclosures

Preregistration: The hypotheses, methods, and analysis plan were preregistered (https://osf.io/ntw6c) prior to data collection. There were major and minor deviations from the preregistration (for details, see Supplementary Table 1). **Materials:** All experimental materials are publicly available, except for copyrighted music scores (https://osf.io/v9y7z). **Data:** Due to ethics restrictions, raw audio recordings cannot be shared. Analyses begin with preprocessed annotated data. All other primary data are publicly available (https://osf.io/v9y7z). **Analysis scripts:** All analysis scripts are publicly available (https://osf.io/v9y7z).

Methods

Participants

Based on power analyses using G*Power 3.1 (Faul et al., 2007) we determined a target sample size of 52 participants. This was informed by two previous studies and the corresponding models used solely for power estimation: (a) a paired-samples t-test model (d = 0.35, based on ηp^2 = 0.110, from Jentzsch & Braun, 2022) to compare musical performance across FOA conditions, and (b) a correlation model (r = .35, −.40 ; from Arbuzova., in prep) to test the modulation of metacognition in the FOA effect. The estimated required sample sizes were 52 and 40, respectively; we adopted the larger value to ensure sufficient power for the planned analyses.

Anticipating potential exclusions according to our preregistered criteria (e.g, task accuracy; see the *exclusion criteria* section below), we recruited 65 participants (18 female, 47 male, M = 26.57 SD = 6.1 years). As our exclusion criteria required some participants to be excluded from some analyses but not from others, the final sample size varies by analysis and is indicated accordingly.

Participants were recruited via mailing lists of the University of Tübingen and word of mouth. All were fluent in English and/or German, had normal or corrected-to normal vision and hearing, and reported no psychological or neurological conditions. Sixty-three participants were right-handed and two were mixed-handed, as assessed by a short version of the Edinburgh Handedness Inventory (rEHI; Veale, 2014). All participants were amateur guitarists (M = 11.36 SD = 7.90 years of experience), with basic knowledge of tablature and/or music reading, and some experience with classical or electric guitar. Their skill levels, estimated based on guidelines for the Associated Board of the Royal Schools of Music (ABRSM) grading system (see below), ranged from Grade 0 to 8. Participants provided written informed consent and received compensation of €10 per hour, bringing the estimated total payment to €45 on average.

Apparatus

Participants completed a music performance task and a motor metacognitive task using two Yamaha (Hamamatsu, Japan) C40 classical guitars, one for each task. For the metacognitive task, a Luthier removed the frets and all other visual fret markings from the guitar. Both experimental tasks were designed using the Unity software (San Francisco, USA), and the UXF toolbox (Brookes et al., 2020).

Hand and finger movements were tracked using 14 VIPER™ electromagnetic motion tracking sensors (Polhemus, Vermont, USA), each weighing less than 1g and measuring approximately 1mm in diameter **(Fig. 1b)**. The system tracked position and orientation across 6 degrees of freedom at 60 Hz by detecting disturbances in a magnetic field. Sensor positions were rendered in real-time on a computer screen, with hand movements displayed relative to the guitar. To minimize measurement noise caused by electromagnetic field interference, participants removed any metallic jewelry prior to testing.

For the music performance task, participant's playing was recorded using a GL21 Lanen microphone (Prodipe, Les Sables d'Olonne, France) and an M-Track solo audio interface (M-Audio, Cumberland, Rhode Island) for signal amplification and AD/DA conversion. During the metacognitive performance task, participants wore HD-660 Pro noise-cancelling headphones (Superlux, New Taipei City, Taiwan) through which they heard notes generated via the Maestro Midi Player Tool Kit (MPTK) library (PaxStellar, GNU General Public License), based on their finger positions and task-specific manipulations.

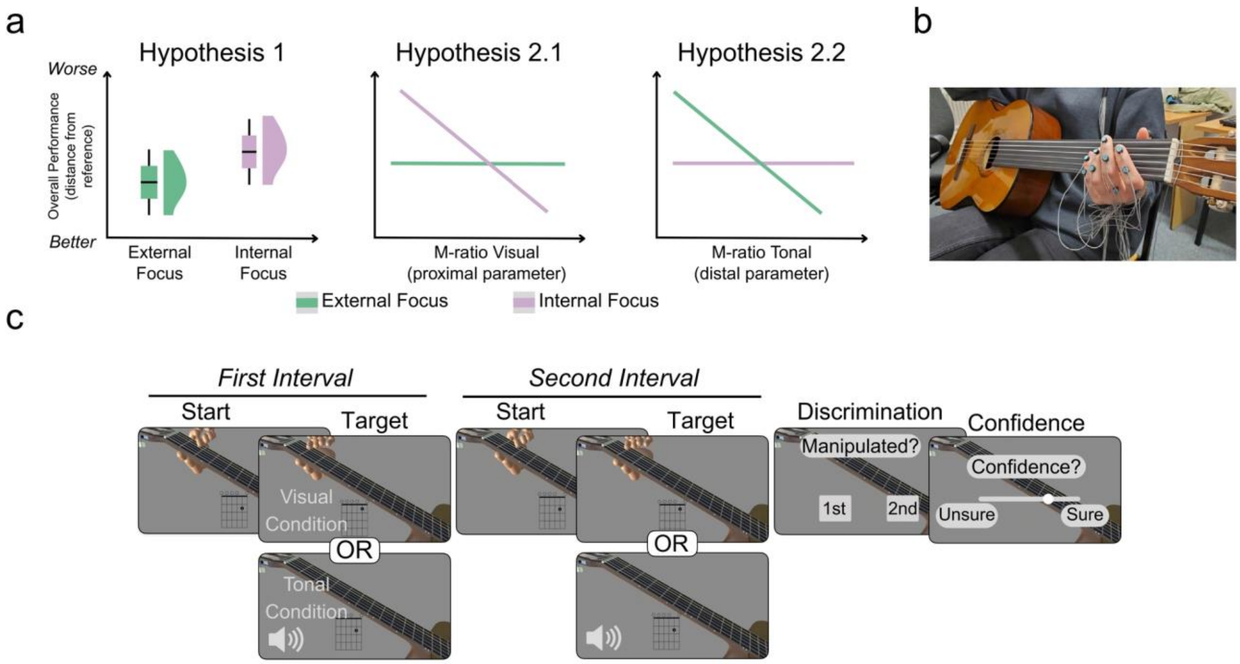

Fig. 1. Hypotheses, experimental setup and task paradigm for assessing metacognitive ability. (a) Predicted outcomes based on the main hypotheses. An external focus is expected to enhance performance compared to an internal focus (left), with the effect moderated by metacognitive ability: a higher m-ratio in the visual condition (proximal parameter) is predicted to improve performance under an internal focus (middle), whereas a higher *m-ratio* in the tonal condition (distal parameter) is predicted to improve performance under external focus (right). (b) Placement of 14 motion sensors on the participant's fretting hand (i.e., left hand), with an additional sensor on the headstock just beside the nut of the guitar to track the position of the hand relative to the guitar. (c) Trial structure of the metacognitive guitar task. In a Two-Interval Forced Choice task, participants made two real-time finger movements along a guitar string, each corresponding to a separate interval, with one interval involving a spatial manipulation. In the visual condition (top) participants viewed the movements rendered on a virtual hand. In the tonal condition (bottom), they heard the resulting pitch but did not see the movements on-screen.

Participants first discriminated which movement was manipulated and then rated their confidence.

Procedure

Questionnaires. Before the first experimental session, participants received an email with links to complete questionnaires online. We built the questionnaires using lab.js (Henninger et al., 2024) and hosted them on a local server from the University of Tübingen running JATOS (Lange et al., 2015). Questionnaires, administered in English, included: the Edinburgh Handedness Inventory — Short Version (Veale, 2014); the Basic Guitar Skill Questionnaire: Developed based on both skill level descriptions from the ABSRM (2019) and the Oldham Music Center (2024), and the Music Experience Questionnaire (Jentzsch et al., 2014); the Metacognitive Awareness Inventory (MAI; Harrison & Vallin, 2018; Schraw & Dennison, 1994); the Strategies for Learning Questionnaire — A short music practice adaptation (MLSQm-7): Based on the "Metacognitive Self-Regulation" subscale of the Motivated Strategies for Learning Questionnaire (MLSQ; Pintrich et al., 1991); and the "Behavioral" subscale of the Self-regulated measure (Miksza, 2012).

After completing all questionnaires, participants received a follow-up email with a musical score (shared with permission and adapted using the Soundslice platform; Holovaty et al., 2024) that included TAB notation, an audio recording of their assigned piece, and instructions to practice the piece for ten consecutive days. We asked them to keep an approximate count of their practice attempts. Based on their Basic Guitar Skill Questionnaire results, participants were assigned one of four possible pieces: *Lightly Row* (Folk Song, 2018) and *Allegro* (Giuliani, 2018) from Volumes 1 and 4 of the Suzuki Method School for Guitar (2018), respectively, or *Jasmine Flower* (Trad. Chinese, 2018) and *Musette BWV Ahn. II 126*

(Bach, 1722/2018), from Grades 1 and 5 of the 2019 ABRSM (2018) syllabus, respectively. To examine the within-participant effects of FOA on music performance while avoiding ceiling or floor effects, we assigned each participant a piece that met their skill, rather than ask all participants to play the same piece. If a piece was perceived as too difficult by the participant at the outset, they were given an easier alternative. To further accommodate individual differences in participants' abilities, eight participants were instructed to perform only the first eight bars, as they were unable to play the full piece. Due to this individualized arrangement, music performance was not comparable across participants.

After completing the first task in the experimental session, participants filled out two additional questionnaires: the Assessment of Piece Difficulty (following Williams et al., 2023) and the Practice Style Assessment Questionnaire (following Williams et al., 2023). All customized questionnaires and their scoring criteria are available in the Supplemental Material**.**

Music Performance Task. For the first task in the experimental session, participants performed the assigned piece on the standard classical guitar under three conditions: no instruction (baseline), external focus, and internal focus. Participants were allowed a brief practice before performing each condition to adjust to the guitar. Before each trial, they heard four metronome beats matching the tempo indicated on the score. After a cue sound signaled the start of recording, they began playing. While playing, we asked that participants keep their eyes on the score at all times, regardless of the attentional focus instruction, following recommendations from the original FOA paradigm (Wulf, 2013).

Instructions were based on previous music adaptations of the paradigm (Duke et al., 2011; Jentzsch & Braun, 2022) and were presented as follows: In the no-instruction condition, participants were asked to "*Play as you normally do*". In the external focus condition, the instruction was to *"Focus on the sound of the music"*. And for the internal condition : *"Focus on the precision of your finger movements"*.

Participants played the piece three times per condition for a total of nine trials. As in previous studies (Atkins, 2017; Atkins & Duke, 2013), the baseline (control) trials always occurred first to avoid any potential bias in focus during these trials caused by the external or internal instructions. We also interleaved trials from the remaining two conditions to control for potential task order confounds (Mornell & Wulf, 2019). After each trial, participants rated how well they followed the focus instructions on a continuous 0-1 scale ranging from "*not at all*" to *"perfectly*" (Allingham & Wöllner, 2022) and had the opportunity to provide additional comments.

Metacognitive Guitar Task. Participants performed two conditions of the metacognitive task, each involving the same basic structure: a Two-Interval-Forced-Choice (2IFC) discrimination (first-order or Type I task) followed by a confidence rating (second-order, Type II task). On each trial, participants made two movements along a guitar string, one per interval, guided by a guitar tablature shown on screen. Participants were always instructed to position their index finger on a starting note and move one fret (one semi-tone) either up or down the fretboard, along a single string, to reach an ending note. A virtual hand, rendered in real time on the screen, moved along the virtual fretboard based on the measured sensor positions. In one of the two intervals, the position of the virtual hand was shifted along the direction of the length of the neck.

In the visual condition, this manipulation caused the on-screen finger to move a given percentage more or less than the actual participant's finger movement. The real guitar's frets were removed to eliminate tactile cues, requiring participants to rely on motor commands and proprioceptive information to determine their finger positioning (**Fig. 1c**). Participants had visual — but no auditory — information on their finger position on the screen (a proximal movement parameter). To discriminate the manipulated movement, participants had to compare proprioceptive information with visual information from the virtual hand on the screen (**Fig. 1c, top**).

In the tonal condition, the same manipulated movement produced a pitch variation corresponding to the virtual hand's position relative to the guitar. The tone corresponding to the finger's actual or manipulated placement was delivered through headphones. Importantly, participants received auditory feedback only (a distal movement parameter), as the virtual hand was no longer displayed on the screen once the cue to move appeared (**Fig. 1c, bottom**). To identify the manipulated interval, participants compared proprioceptive and computer-generated auditory information. Note that participants never plucked the strings on the real guitar.

After completing the movements, participants used a mouse with their right hand to respond first to a discrimination question (report which movement they thought had been manipulated) and second to rate their confidence that their discrimination response was correct on a slider ranging from low (left) to high (right) confidence. They were encouraged to use the full scale to report their confidence (**Fig. 1c**)

We adapted the difficulty of the discrimination task to each participant's ability, using a 2-down-1-up adaptive staircase on the magnitude of the spatial alteration. This procedure aimed to achieve an average accuracy of approximately 71% for each participant (Leek, 2001). Across all participants, the staircase was constrained by preset values: a starting manipulation amount of

30% for the visual condition and 45% for the tonal condition. The minimum (2%), maximum (100%) and step size (2%) were identical for both conditions.

The order of the visual and tonal condition was counterbalanced across participants, with a 10-15 minute break provided in between. Each condition consisted of 200 trials preceded by a set of up to 20 practice trials. If participants did not understand the task, or otherwise wanted more practice, they repeated the practice block. Short, self-paced breaks were allowed after every 20 trials. The complete experimental session, including the music performance task and the metacognitive task, lasted approximately 3.5 hours in total.

Data Analysis

Questionnaire-based Metacognitive Measures. Participants completed the MAI scale, which consists of 19 statements rated on a five-point Likert scale based on how much they agreed with each one (1 = "not at all typical of me", 5 = "very typical of me"). This scale assesses two dimensions of metacognition: Knowledge of cognition and Regulation of cognition. Scores for all items within each dimension were averaged separately, resulting in two final scores, with higher scores indicating greater metacognitive ability (Harrison & Vallin, 2018). Additionally, participants completed the MLSQm-7 questionnaire, which contains seven items rated on a five-point Likert scale (1= "not at all true of me", 5 = "very true of me"). The overall score was calculated as the mean of the items, where higher values also indicate higher ability.

Music Performance Analysis. First, we converted and edited the reference scores from the ABRSM and Suzuki books into Musical Instrument Digital Interface (MIDI) format using the Soundslice platform (Holovaty et al., 2024). When two or more notes were played simultaneously in both participant and reference audios files, we only considered the main melody (the higher register part) of each piece and excluded any notes on the bass line. In participant recordings, these exclusions were made while cleaning the automated annotations (see below). This was necessary due to the current limitations of automatic transcription and alignment methods in accurately processing polyphonic music (Lerch et al., 2020; Lian et al., 2023; Müller, 2021).

We preprocessed the participant and reference recordings using Audacity version 3.7.1 (Audacity Team, 2024), which involved trimming the first and last eight bars according to the score and adjusting the volume to help with feature detection. Then, pitch and rhythm features (frequencies and onsets) of each note played were extracted from the audio recordings using Sonic Visualizer (Cannam et al., 2010). The resulting automated annotations were manually cleaned through visual and audio inspection. The cleaning process included removing false positives, adjusting octave errors, adding missing notes and addressing pitch inconsistencies. Minor performance errors (e.g., lightly hitting unintended strings) were disregarded. Finally, the accuracy of the annotations was verified by listening to the annotations without the original recording. Two of the authors independently carried out the annotation process, with each responsible for analyzing a specific subset of songs and participants. In those cases where ambiguities arose, they were resolved through discussion and consensus. The final output for each performance consisted of two lists: one for onset timings and one for pitch frequencies.

Subsequent analyses were executed using MATLAB (version R2024b The MathWorks Inc., Natick, MA, USA, 2024) with the MIDI toolbox (Eeerola & Toiviainen, 2004), the MIR Toolbox (Lartillot et al., 2008), and the Dynamic Time Warping (DTW) source code from the *Audio Content Analysis* book (Lerch, 2023). The pitch and onset annotations were preprocessed by converting the extracted frequencies into the closest MIDI note values. Inter-onset interval (IOI) values, which measure time accuracy between consecutive notes, were calculated by subtracting the onset time of each note from the following note's onset time (Müller, 2021). The reference score was aligned with the participant's performance using DTW, which computes the optimal alignment path by minimizing the accumulated distances between two sequences with different lengths (Müller, 2007). From this alignment, rhythm accuracy was assessed by the cost of onset alignment. Pitch accuracy was measured using the pitch error ratio, defined as the number of extra, missed or substituted notes divided by the total number of notes expected to be played according to the reference score (Gururani et al., 2018; Lerch, 2023).

To keep the analyses both comprehensive and manageable, we only analyzed the first and last eight bars of each performance; for those who played only eight bars (see the Procedures section), we analyzed the entire performance. We analyzed these two sections separately. For each section, pitch error ratios and rhythm cost were calculated, then combined by summing the pitch error ratio and rhythm costs across both sections.

To quantify overall performance, we first applied log transformations to the rhythm cost and pitch error ratios separately to reduce skewness. These log-transformed variables were then normalized (z-scored) between participants. Finally, for each participant, an overall performance measure was computed as the average of their normalized rhythm cost and pitch error ratios, with lower values indicating better performance. To facilitate the interpretation and visualization of results, we deviated from our pre-registered plans: although intended as exploratory, we used the recordings in the no-instruction condition as a measure of baseline (control) performance. We subtracted each participant's mean music performance in the baseline (control) conditions from their corresponding internal and external condition trials, such that 0 corresponds to baseline (control) performance, negative values indicate above baseline performance and positive values indicate below baseline performance. Because some participants did not play the full song, each performance was assessed relative to the reference that matched only the section they played of the assigned song.

Measure of Metacognitive Efficiency. To estimate metacognitive ability, we used *m-ratio,* calculated as the ratio of metacognitive sensitivity (*meta-d'*) to sensitivity (*d'*) (Maniscalco & Lau, 2012). The index *d'* reflects Type I performance: how accurately participants discriminated the interval containing the manipulation. In contrast, *meta d'* reflects performance on the Type II task: how well participant's confidence ratings distinguish between correct and incorrect responses. Because *meta-d'* is influenced by Type I performance, dividing it by *d'* yields a performance-adjusted metric, known as metacognitive efficiency (*m-ratio*). Theoretically, an *m-ratio* of 1 indicates optimal use of sensory information for metacognitive tasks, while an *m-ratio* of 0 reflects poor use of sensory information. However, in practice, *m-ratio* can fall outside the 0-1 range due to misestimations (Guggenmos, 2021; Rausch et al., 2023) or accumulation of additional evidence after the decision has been made (Mamassian & De Gardelle, 2024; Pleskac & Busemeyer, 2010). We calculated these values using the R package 'metaSDT' with a maximum likelihood fitting procedure (Craddock, 2021). Since the model requires discrete confidence ratings, each participant's continuous confidence reports were first scaled within each participant to range from 0 to a 100 and then binned into a five-point scale, eliminating idiosyncratic individual differences in scale use.

Statistical Analysis. In our preregistration, we planned to use both frequentist and Bayesian models. Because Bayesian proved more robust to model assumption violations, we present them in the main text and report the preregistered frequentist analyses in the Supplementary Material.

We tested our main hypotheses by implementing Bayesian mixed models through the 'brms' package (Bürkner, 2017, 2018) in R (R Core Team, 2025). Bayesian models were estimated with 4 Markov chain Montecarlo (MCMC) chains of 15,000 iterations, including 5000 warm-up samples and no thinning. We visually assessed the chains for convergence, inspecting the trace plots and by confirming that the Gelman Rubin diagnostic ($\hat{R}$) was close to 1 for all model parameters. As we expected FOA to vary across individuals, all models include random intercepts for participants and random slopes for FOA. Furthermore, to account for repeated performances of the same song, we also included trial number as a fixed effect (**Table 1** shows model syntaxes). To better accommodate skewed distributions in our outcome variables, we modeled the response distribution using a Student's t distribution. This model substantially outperformed the Gaussian alternative as indicated by a significantly higher expected log predictive density (ELPD) in leave-one-out cross validation, ELPD diff = –68.18, *SE* = 17.99 (Vehtari et al., 2017). All models used the default weakly informed priors, which include normal priors for fixed effects and student t-test priors for standard deviations and residual variance (Bürkner, 2018).

We calculated Bayes factors (BF_{10}) using the 'bayestestR' package in R (Makowski et al., 2019) using each model as the numerator and an identical model excluding the single fixed effect tested (but containing identical random effect structures), as the denominator. Finally, we computed the Bayesian version of R^2 for regression models (Gelman et al., 2019). Semi-partial R^2 for predictors and interactions are also included in the Supplemental Material. For exploratory analyses corresponding to metacognitive performance in visual and tonal conditions, Bayes Factors were calculated from posterior probabilities provided by the BFpack R package (Mulder et al., 2019).

Table 1

Regression Models for Main Hypotheses

Hypothesis	**Model Formula**
1 Musical performance will improve with an external focus of attention	music performance ~ foa + trial number + (1 + foa | participant)
2. 1 Participants with higher *m-ratio* in the visual condition will have better musical performance under an internal focus of attention.	music performance ~ (foa * *m-ratio* visual) + trial number + (1 + foa | participant)
2.2 Participants with higher *m-ratio* in the tonal condition will have better musical performance under an external focus of attention.	music performance ~ (foa * *m-ratio* tonal) + trial number + (1 + foa | participant)

Note: Music performance refers to three outcome measures: overall performance, pitch error ratio and rhythm cost. Each model was fit separately for each outcome measure.

In line with our preregistration, we also conducted frequentist hypothesis testing by fitting linear mixed models using the ‘lme4’ (Bates et al., 2015) package in R. All hypotheses were tested using a two-tailed significance test with an alpha level set at 0.05. However, because frequentist models often exhibited near-singular fits and near-zero variance in the parameter estimates, we opted to deviate from our pre-registered plan and report, for all analyses, only Bayesian R^2 estimates. Semi-partial R^2 values were calculated as the difference in Bayesian R^2 between full and reduced models for each predictor. Bayesian linear mixed models allow for greater flexibility with the distributions and provide more robust inference when assumptions are violated (Fong et al., 2010; Lachos et al., 2009; Rosa et al., 2003). Overall, results from Bayesian and frequentist analyses were broadly consistent, except where explicitly noted.

Exclusion criteria. As pre-registered, individual trials from the metacognitive task were excluded if the Type I reaction time (RT) was below 0.2 (suggesting a false or accidental button press) or above 8 seconds (which could indicate inattentiveness). Participants could also omit a trial by pressing a skip button if they were distracted or realized they had made a mistake while computing their responses; these trials were excluded from analysis.

Across the 200 trials per condition, in the spatial condition an average of 2.86 trials (*SD* = 4.84) per participant were excluded due to RT filtering and 3.86 (*SD* = 6.07) trials due to skipped responses. In the tonal condition, an average of 7.38 (*SD* = 8.71) were excluded due to reaction RT and 6.26 (*SD* = 5.58) trials were due to skipped responses.

Additionally, an unforeseen issue arose in the tonal condition: an adjustment to the maximum percentage of spatial manipulation led to some trials producing auditory feedback corresponding to an impossible pitch (i.e., below the open string). These trials were excluded despite not being preregistered, as participants' decisions were likely influenced by the implausibility of the auditory feedback rather than the intended manipulation. On average, 23.60 (*SD* = 12.83) trials were excluded for this reason (out-of-range exclusion only applied in the tonal conditions).

At the participant level, datasets were excluded if Type I accuracy for a given condition was below 60% or above 85%, indicating that the staircasing procedure did not effectively maintain the difficulty of tasks within the intended range. Only one data set from the tonal condition was excluded due to performance under 60%. Separately, we applied a second participant-level criterion. We deviated from the preregistered plan and instead of excluding participants who skipped more than 20% of trials, we excluded those who lost a total of more than 30% of trials (i.e., skipped plus out-of-range trials). If a participant exceeded this threshold in either of the two conditions, the entire dataset from that participant in a given condition was excluded from these analyses. Applying this criterion, 12 additional data sets from the tonal condition were excluded. Importantly, this criterion still allowed a sufficient number of trials to generate reliable estimates (Rahnev, 2025). To assess the impact of this deviation, we re-ran all main analyses using the original preregistered exclusion criteria. Results and conclusions remained unchanged, indicating our findings are robust to the specific threshold. Further details are available in the Supplemental Material.

Because some statistical analyses required valid *m-ratios* from both conditions, participants excluded from either condition were also removed from all analyses involving metacognitive measures, resulting in a final sample of 52 participants. No participant was excluded from the music performance task; therefore, the full sample of 65 participants was retained for the statistical tests that did not involve *m-ratios.*

Results

Manipulation Rating. During the music performance task, participants rated how well they were able to follow the FOA instruction. Overall, participants rated their ability to follow the external focus instruction higher (M = 0.71, SD = 0.17) than the internal focus instruction (M = 0.67, SD = 0.10) with weak evidence favoring the difference, BF_{10} = 2.61, $t(64)$ = –2.54, p = .01, d = –0.32. Notably, there was spread in the reported values, the distributions were negatively skewed (external: skewness = –0.92; internal: skewness = –0.77) with median ratings exceeding the means (external: 0.74 vs. 0.71; internal: 0.70 vs. 0.67), suggesting a tail of lower ratings for some participants.

To ensure that participants were sufficiently following the instructions in both conditions, one-sample tests compared each participant's mean rating in each condition against a minimum threshold of 60%. Ratings in both conditions exceeded this threshold: internal focus (BF_{10} = 29.47, $t(64)$ = 3.49, p < .001, d = 0.43) and external focus (BF_{10} = 4,548,318.61, $t(64)$ = 6.93, p < .001, d = 0.86).

Focus of Attention Effect. We tested the effects of FOA and trial number on overall musical performance using a linear mixed-effects regression model. Since performance was inversely scored, we hypothesized that playing with an external FOA would lead to lower distances (i.e., closer alignment to the target MIDI score) in pitch and rhythm.

There was strong evidence against an FOA effect (BF_{10} = 0.04) on the overall performance distance measure. The coefficient estimate was negligible ($b = -4.88 \times 10^{-4}$, 95% *CI* [−0.03, 0.03]; see **Fig. 2a**). This null effect cannot easily be explained by an unreliable measure of performance: The negative effect of trial number on the overall performance distance (b =–0.02, 95 CI [−0.04,−0.01]) suggests that performance improved over the repetitions across trials, and that these improvements were reflected in the distance measure. While the Bayesian analysis indicated only anecdotal evidence in favor of the null hypothesis regarding trial effects (BF_{10} = 0.68), the frequentist analyses indicated a statistically significant improvement in musical performance over trials (**Table S2**). Overall, the full model explained a moderate portion of the variance (R^2 = .37). The models for pitch and rhythm estimates separately led to similar conclusions and are reported in the Supplemental Material, along with the frequentist estimates.

Importantly, while there was no FOA group-level effect, the random slopes revealed modest variability across participants, suggesting that some individuals were differentially affected by FOA (*SD* = 0.03, 95% CI [0.00, 0.07]). This justified testing our second pre-registered hypotheses, namely whether individual differences in metacognitive ability moderate attentional focus effects. Models included the same structure as before, but with metacognitive ability (*m-ratio*) and its interaction with FOA (**Table 1**).

Metacognitive Ability Modulation. Next, we tested our hypothesis that participants who had higher m-ratio in the *visual* condition would perform better under an *internal* focus of attention (**H2.1**; **Fig. 1a**). Against our expectations, we did not find evidence for the hypothesized interaction between the effect of FOA and visual *m-ratio* (BF_{10} = 0.15, b = −0.03, 95% CI [–0.14, 0.08]), suggesting that the precision of metacognitive representations does not explain performance differences depending on the FOA effect.

There was extreme evidence of no main effect of FOA ($BF_{10} = 7.71 \times 10^{-5}$, $b = 0.02$, 95% CI [–0.09, 0.14]) and moderate evidence of no main effect of *visual* metacognitive ability ($BF_{10} = 0.07$, $b = -0.09$, 95% CI [–0.43, 0.24]). The effect of trial again indicated that performance improved with practice ($b = -0.02$, 95% CI [–0.04, –0.01]), as the confidence interval excluded zero (**Table S3**). However, Bayesian analysis provided only anecdotal evidence ($BF_{10} = 0.80$). The full model explained a moderate portion of the variance ($R^2 = .38$).

We then tested whether participants with higher *m-ratio* in the tonal condition would perform better under an *external* focus of attention (Hypothesis 2.2). Although the interaction coefficient was in the expected direction, results showed no evidence supporting the interaction ($BF_{10} = 0.16$, $b = -0.04$, 95% CI [–0.10, 0.03]), **Fig. 2c**)

As in the *visual* condition analysis, we found extreme evidence of no main effect of FOA ($BF_{10} = 8.9 \times 10^{-5}$, $b = 0.03$, 95% CI [–0.03, 0.09]) and strong evidence for no effect of tonal metacognitive ability ($BF_{10} = 0.06$, $b = 0.07$, 95% CI [–0.14, 0.29]). For trial number effects, although the Bayesian evidence was anecdotal, the credible interval and consistent negative direction of the effect, suggest a small improvement with repetition ($BF_{10} = 0.85$, $b = -0.02$, 95% CI [–0.04, –0.01]); **Table S4)**. The full model explained a moderate portion of variance ($R^2 = .38$).

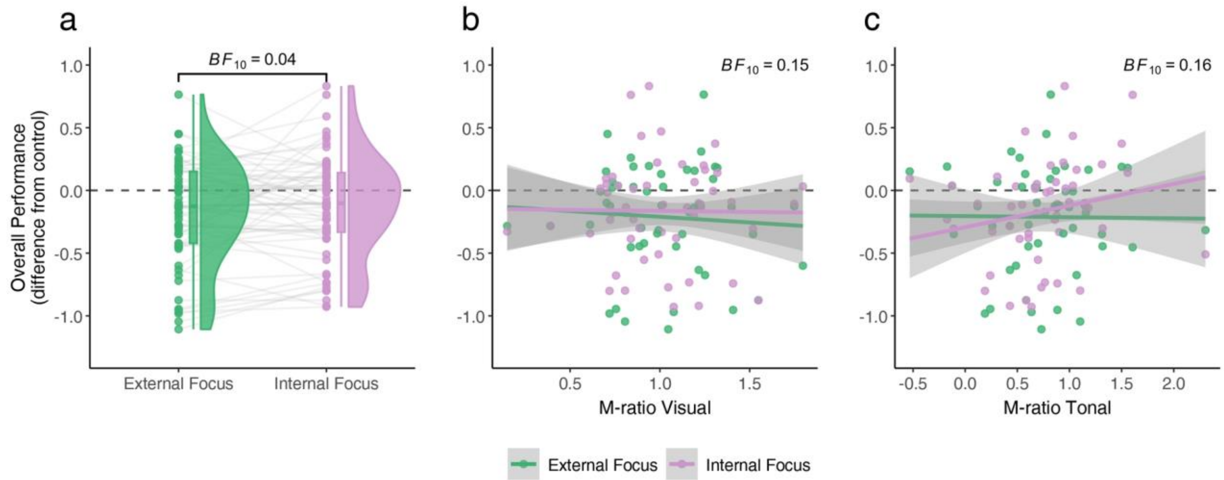

Fig. 2. FOA effects and their interaction with metacognitive ability modulation. (a) Raincloud plot of baseline-corrected overall performance scores (average of normalized pitch and rhythm distance measures, with lower values indicating better performance). Dots represent individual participants (N = 65), densities and boxes show distribution and interquartile range (25th–75th percentiles) BF denotes the main effect of FOA. (b-c) Scatter plots showing the relationship between *m-ratio* and baseline-corrected overall performance across FOA conditions in the (b) visual and (c) tonal conditions (N = 52). Lines show simple linear regressions of the raw data (means), with 95% confidence intervals. BF values correspond to the FOA * *m-ratio* interaction.

Exploratory Analyses

Table 2

Regression Models for Exploratory Analyses

Predictor	**Model Formula**

Expertise as measured by guitar playing experience (score in the Basic Guitar Skill questionnaire)	music performance ~ (foa * guitar skill score) + trial number + (1 + foa | participant)
Expertise as measured by Type I performance (mean staircase value in visual condition or tonal condition)	music performance ~ (foa * mean staircase value) + trial number + (1 + foa | participant

Note: Music performance refers to three outcome measures: overall performance, pitch error ratio, and rhythm cost. Each model was fit separately for each outcome measure.

Preregistered Exploratory Analyses

Following our preregistered plan, we explored possible effects of guitar expertise on music performance. Prior studies presented mixed evidence for the interaction between expertise and FOA in music: Some report benefits of an external focus for trained performers (e.g., singers: Atkins, 2017; pianists: Duke et al., 2011) while others find either no effect or advantages for an internal focus among less experienced musicians (e.g., singers: Atkins & Duke, 2013; wind players: Stambaugh, 2017). Even among experienced wind players, internal FOA has sometimes been associated with more stable performance (Stambaugh, 2019).

To examine the moderation effects of expertise in the context of guitar playing, we fit several linear mixed-effects regression models (**Table 2**) with music performance distance measures as the dependent variable. Expertise and FOA were included as fixed effects, along with their interactions. Each model included a by-participant random intercept and a random slope for FOA. Expertise was measured in two ways: the Basic Guitar Skill Questionnaire score, and skill level in the first-order discrimination judgment of the metacognitive task. For the latter, we used the mean staircase value reached in each of the two task conditions (visual or tonal), with a lower staircase value indicating that participants achieved approximately the same number of correct 2IFC discrimination responses with a lower average manipulation magnitude.

To avoid redundancy, we report here only the statistical results pertaining to the new effects under consideration, namely expertise and their interaction with FOA. All other effects, including the main effect of trial and the null effect of FOA, were consistent with the results previously reported. Full results are available in the Supplemental Material (**Table S5, S6 and S7**).

Expertise as Guitar Playing Experience. We found no credible association between music performance (difference from control) and guitar playing experience, $BF_{10} = 6.20 \times 10^{-5}$, $b = -1.76\times10^{-3}$, 95% CI [–0.01, 0.01] (**Fig. 3**). The interaction between FOA and guitar playing experience was not supported by the data, with decisive evidence against their interaction ($BF_{10} = 0.01$, $b = 1.21 \times 10^{-3}$, 95% CI [-1.68×10^{-3}, 4.21×10^{-3}]). The model explained $R^2 = .37$ of the variance in performance.

Expertise as Average Staircase Value. The data provided decisive evidence against an association between performance and the mean staircased value in the *visual* condition ($BF_{10} = 4.26\times10^{-5}$, $b = -1.57\times10^{-3}$, 95% CI [−0.01, 0.01], **Fig. 3b**). The interaction between FOA and staircased manipulation value was also unsupported, with very strong evidence against the interaction (BF_{10} = 3.51×10^{-3}, b = −1.38×10^{-3}, 95% CI [−3.04×10^{-3}, 2.40 × 10^{-3}], **Fig. 3b**) The model accounted for R^2 = .37 of the variance in performance.

Second, we defined expertise based on participants' mean staircase value in the tonal condition. Again, the data showed decisive evidence against a relationship with performance, BF_{10} = 4.59×10^{-5}, b = 3.31×10^{-3}, 95% CI [−4.63×10^{-3}, 0.01]. Similarly, there was also very strong evidence against an interaction between FOA and staircased manipulation value (BF_{10} = 3.53×10^{-3}, b = −1.30×10^{-3}, 95% CI [−2.67×10^{-3}, 2.44 × 10^{-3}], **Fig. 3b**). The model explained R^2 = .38 of the variance in performance.

To summarize, expertise—whether defined as guitar playing experience or as Type I skill—does not appear to be a critical factor influencing the effects of FOA on performance. FOA effects remained unsupported by the data, as well as its interaction with expertise. Additional analysis using pitch and rhythm performance as separate outcome variables, which revealed similar results, are presented in the Supplemental Material.

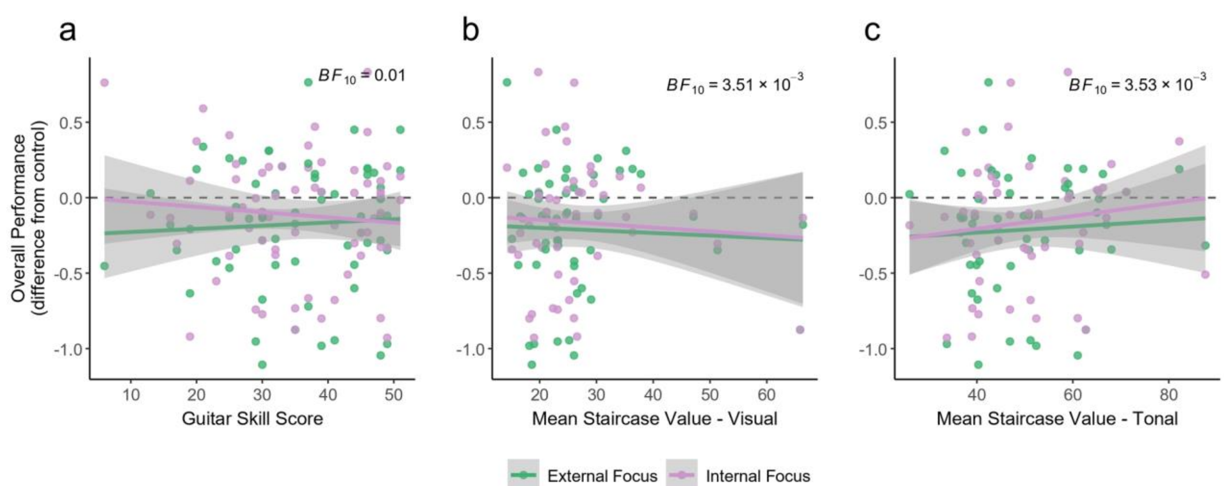

Fig. 3. The data provided evidence against an interaction between FOA effects and expertise. Each participant is represented by two markers in each scatter plot. The panels plot the baseline-corrected overall performance in each FOA condition against the three different expertise measures: (a) guitar skill score (N = 65), (b) mean average staircase value in the visual condition and (c) mean staircase value in the tonal condition (N = 52). The dots represent a participant's average score across trials for each condition. The lines represent linear regression trends with 95% confidence intervals for each FOA.

Metacognition Measurement Alignment across Protocols. As preregistered, we examined the correspondence between different estimates of metacognitive function, specifically self-report questionnaires, and the m-ratio estimates. Because these analyses are accessory to the paper's primary focus, the results are presented in **Table S8** and **Fig. S1** of the Supplemental Material, along with our key interpretative conclusions.

Metacognitive Performance Across Visual and Tonal Conditions. Our working hypothesis (Hypothesis 2) posits that focusing externally would lead to a better performance if a participant's metacognitive efficiency (*m-ratio*) is higher when monitoring tonal (external) information compared to visual (internal) information. Consequently, we would expect a population-level advantage for an external focus reflected in a higher overall *m-ratio* in the tonal condition. To test whether this advantage holds true, we now turn to comparisons of participants' performance and metacognitive efficiency between the two conditions of the task: tonal and visual.

Contrary to expectations, in terms of task performance (*d'*), participants were better able to discriminate the manipulation in the visual (M = 1.15, SD = 0.13) compared to the tonal condition (M = 1.04, SD = 0.21), with very strong evidence supporting this difference (BF_{10} = 51.66, $t(51) = 3.71$, $p < .001$, $d = 0.67$). An analysis of reaction times revealed a similar pattern, as response times for the discrimination task were substantially faster in the visual condition (M = 1.62s, SD = 0.44s) than in the tonal condition (M = 2.56s, SD = 0.56s; $BF_{10} = 3.38 \times 10^{17}$, $t(51) = -15.21$, $p < .001$, $d = -1.82$; **Fig. 5a**). However, the mean confidence was similar between visual (M = 55.37, SD = 10.38) and tonal conditions (M = 57.51, SD = 12.34), with moderate evidence for the lack of a difference (BF_{10} = 0.31, $t(51) = -1.24$, $p = .220$, $d = -0.19$, **Fig. 5b**). Metacognitive sensitivity (meta d') was higher in the visual (M = 1.15, SD = 0.33) than in the tonal condition (M = 0.78, SD = 0.47) with decisive evidence indicating this difference (BF_{10} = 24080.08, $t(51) = 5.68$,$p < .001$, $d = 0.92$, **Fig. 5c**). Metacognitive efficiency (*m-ratio*), which controls for first-order performance, was also higher for the visual (M = 1.01, SD = 0.32) compared to the tonal condition (M = 0.75, SD = 0.49), with strong supporting evidence (BF_{10} = 24.48, $t(51) = 3.44$, $p = .001$, $d = 0.63$, **Fig. 5d**). Because some participants had *m-ratios* below zero, we reran our main analyses with those cases excluded. Our main conclusions remained unchanged, with full details provided in **Tables S9** and **S10**. All statistical comparisons were conducted used paired-samples t-tests after confirming normality of the difference scores (all Shapiro-Wilk tests $p > .05$).

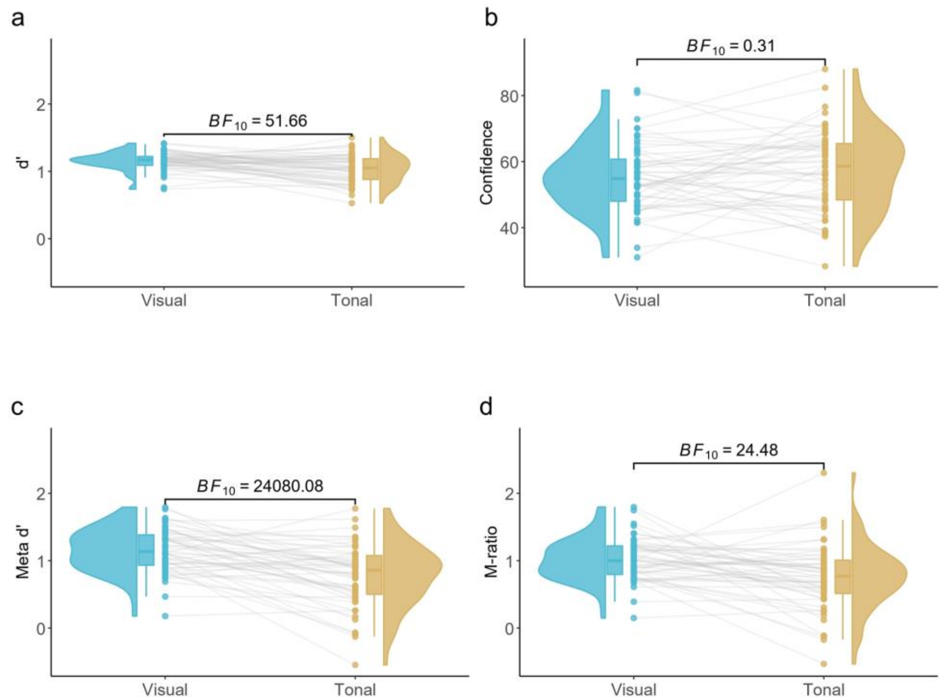

Fig. 4. Performance in the visual and tonal conditions on the metacognitive task. (a) d′: discrimination performance (b) mean confidence (c) *meta-d′*: metacognitive sensitivity, and (d) *m-ratio:* metacognitive ability. Each plot displays individual participant data points (N = 52), density distributions, and interquartile ranges (25th–75th percentiles).

Given the significant differences we found in the *m-ratios* between the visual and tonal conditions, we sought a potential explanation. Prior research suggests that when participants' movements deviate from instructions, but the experimenters present a choice option that matches the instructions, participants may confidently —but incorrectly — attribute the successful outcome to their own execution (Charalampaki et al., 2023). In our task, this could mean that participants identified the interval differing from the instructed semitone as "manipulated", assuming they had performed the movement correctly, rather than recognizing the deviation from their actual movement (even when one of the intervals actually matched what they performed). Such intention-driven misattributions would inflate confidence on incorrect trials, thereby reducing metacognitive efficiency. Importantly, this does not imply a global increase in confidence or lack of metacognitive access. Rather, misattributions would occur specifically on incorrect trials because intentions and outcomes diverge. Arguably, these misattributions may have been more prevalent in the tonal trials, where participants likely held narrower priors regarding what constitutes a correct interval. Because pitch perception is continuous, even slight deviations from a semitone can sound wrong, prompting participants to consider those outcomes as manipulated. In contrast, success in the visual condition was defined by landing on the correct fret—a discrete and spatially broader target—offering a wider margin for perceived success and reducing the likelihood of misattribution. In real guitar-playing contexts, small deviations in finger placement within a fret are unlikely to affect the produced pitch, making the visual domain more tolerant to motor imprecision and less prone to intention-outcome misalignment.

To examine this possibility, we first considered two types of trials, that depended on the interaction between a participant's motor error and the value of the manipulation on a specific trial. We defined *Aligned* trials as those in which the manipulated interval was also the one in which the outcome (tonal or visual distance) deviated most from the intended movement. Conversely, we call trials *Conflicting* when the outcome of the manipulated interval was in fact closest to the intended movement, such that the manipulation effectively compensated for a motor error (**Fig. 5a**).

We then compared overall accuracy between *Aligned* and *Conflicting* trials. A greater accuracy drop on *Conflicting* trials relative to *Aligned* trials would suggest participants relied on the outcome's deviation from their intention, rather than the actual manipulation. We expected to find this pattern to be stronger in the tonal condition, which, for the reasons mentioned above, we speculated would be more susceptible to intention-driven misattribution biases. We fit a logistic regression model predicting trial accuracy from condition, conflict status (conflict vs. aligned) and interaction. Bayes Factors were calculated from posterior probabilities provided by the BFpack R package (Mulder et al., 2019).

Indeed, the interaction between condition and conflict status was strongly supported ($BF_{10} = 2.6 \times 10^{12}$), with performance dropping significantly more on conflict trials in the tonal condition than in the visual condition (OR = 0.59, 95% CI [0.52, 0.67], $p < .001$). These results suggest that participants chose the interval with the outcome or intention deviation, rather than on manipulation in the tonal condition when cues were in conflict (**Fig 5b**). The model also revealed a significant main effect of condition: there was higher accuracy in the tonal condition compared to the visual condition (Odds Ratio (OR) = 1.24, 95% CI [1.12, 1.36], $p < .001$, $BF_{10} = 122.6$). However, there was no main effect of conflict (OR = 0.92, 95% CI [0.84, 1.00], $p = .06$, $BF_{10} = 0.09$), indicating that conflicting cues did not impart accuracy across conditions, but had a specific impact in the tonal condition.

Next, to investigate whether the observed drop in performance under conflict could explain the differences between m-ratios across conditions, we examined participants' confidence ratings. If participants misattribute movements with outcomes closest to the target to themselves (i.e., the movement that corresponded to one semitone difference), we expected confidence to be inflated on incorrect *Conflicting* trials relative to incorrect *Aligned* trials in the tonal condition. We fit a linear model predicting confidence from conflict status, condition, accuracy, and their interaction. The model revealed a significant three-way interaction ($b = -0.09$, 95% CI [–0.13, –0.06], $p < .001$, $BF_{10} = 1925.92$), supporting the idea that in the tonal condition, confidence ratings were less sensitive to accuracy, with overall confidence elevated regardless of whether responses were correct, which would reflect impaired metacognitive efficiency (**Fig. 5b**). We further observed a robust interaction between condition and conflict ($b = 0.09$, 95% CI [0.06, 0.12], $p < .001$, $BF_{10} = 3.9 \times 10^5$), with confidence higher on conflict than aligned trials in the tonal condition (**Fig. 5b**). There were no main effects of condition ($b = –4.74 \times 10^{-3}$, 95% CI [–0.03, 0.02], $p = .70$, $BF_{10} = 0.01$) or conflict status (b = 0.01, 95% CI [–0.01, 0.04], p = .18, $BF_{10} = 0.03$), with strong Bayesian evidence favoring the null hypotheses. Accuracy strongly predicted confidence overall ($b = 0.18$, 95% CI [0.17, 0.20], $p < .001$, $BF_{10} = 2.5 \times 10^{83}$).

Last, to confirm that this difference in mean confidence between accuracy conditions affected measures of metacognitive efficiency, we created two subsets of data: one containing only conflict trials and another containing only aligned trials, and calculated *m-ratios* separately for both. Note, however, that the number of trials was lower than recommended for the *m-ratio* estimations calculation: aligned–visual, $M = 92.57$ (range = 64–115); aligned–tonal, $M = 74.73$ (range = 56–96); conflict–visual, $M = 101.21$ (range = 70–121); and conflict–tonal, $M = 90.42$ (range = 78–105). There were no main effects of condition ($b = –0.20$, 95% CI [–0.42, 0.02], $p = .079$, $BF_{10} = 0.56$) or alignment ($b = –0.09$, 95% CI [–0.31, 0.14], $p = .445$, $BF_{10} = 0.17$) and the interaction between condition and alignment was small ($b = 0.08$, 95% CI [–0.23, 0.39], $p = .616$, $BF_{10} = 0.15$) providing moderate evidence in favor of the null (**Fig. 5c**).

Although m-ratio comparisons between *Conflicting* and *Aligned* trials did not show the expected pattern—likely due to too few trials and estimation noise—it was only in the tonal condition that a significant accuracy drop on conflict trials was observed alongside misattribution errors (i.e., higher confidence on incorrect responses). This suggests a possible explanation for the reduced metacognitive efficiency relative to the visual condition.

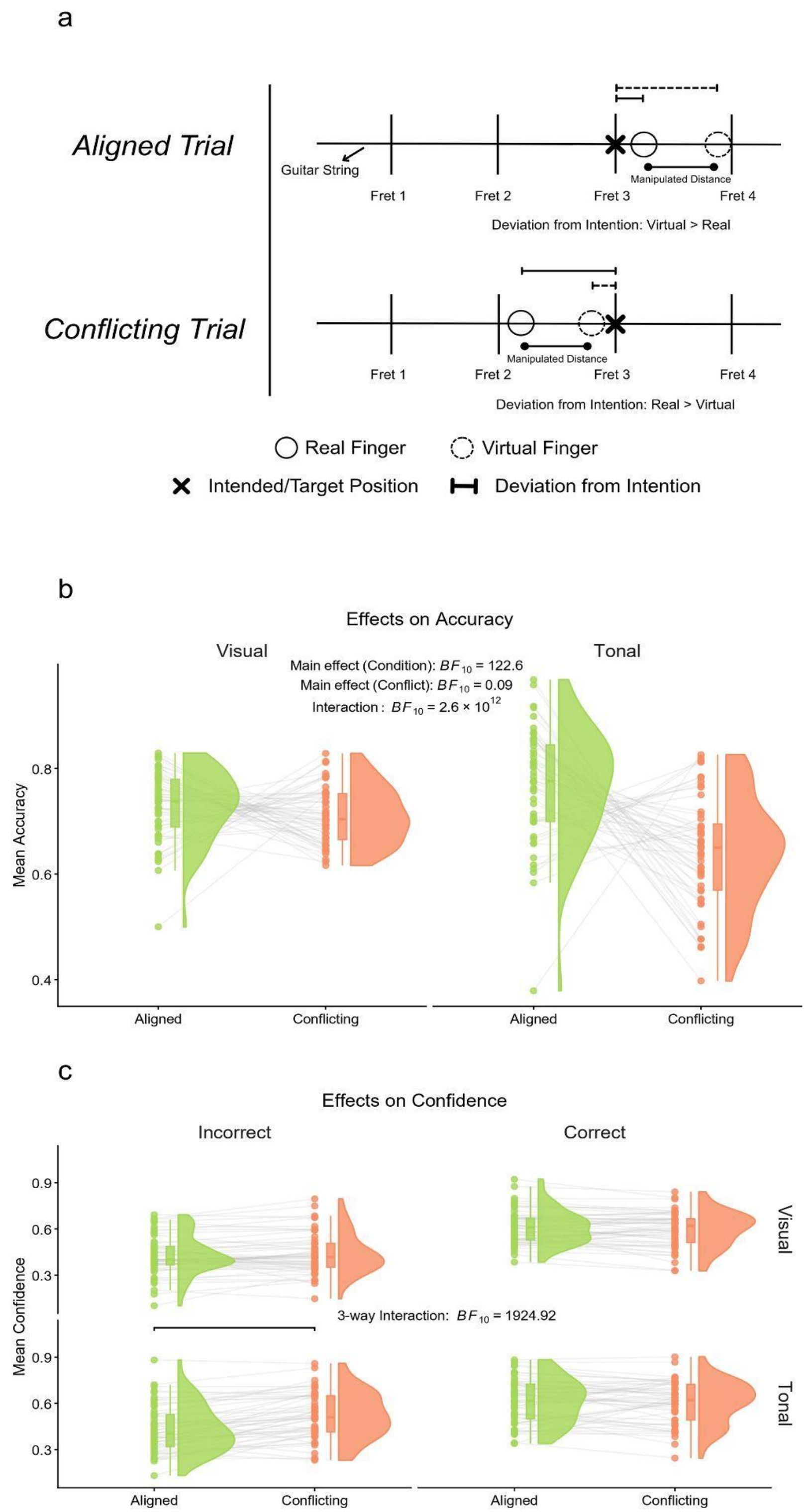

Fig. 5. (a) Illustration of trial types. On *Aligned* trial (top), the spatial manipulation reduced the movement relative to what the participant actually played, causing the virtual finger (dotted) to deviate from the instructed target position (×). On a *Conflicting* trial (bottom), the participant's real hand deviation (solid) was partially corrected by the same spatial manipulation, making the virtual finger (dotted) appear closer to the intended note (×). (b) Raincloud plots showing mean accuracy and (c) mean confidence across visual and tonal conditions, split by *Aligned* and *Conflicting* trials and accuracy (correct and incorrect). Brackets highlight the relationship driving the three-way interaction. Individual participant data (N = 52) are shown as dots; distributions and interquartile ranges (25th–75th percentiles) are depicted with densities and boxes.

Discussion

Is a musician's performance enhanced by focusing on the sound while minimizing attention to bodily movements? In this study, we tested whether an external focus improves motor performance, as dominant FOA theories suggest, and whether its effectiveness depends on how the focus aligns with metacognitive ability. Music performance did not improve under an external compared to an internal focus, nor was this relationship mediated by metacognitive ability. These results challenge the assumed universality of the FOA effect and highlight the need for further research into precise mechanisms.

Rethinking External Focus Superiority in Music Performance

Contrary to our preregistered hypothesis and prior sports literature, we found strong evidence that focusing externally does not improve motor performance more than internally. Guitarists in our study showed comparable pitch and rhythm accuracy under both attentional focus conditions. These results suggest that FOA may operate differently in music than in sports. In music, internal instructions often emphasize movement technique (e.g., finger placement or breath control), which may not hinder execution if aligned with task-relevant goals (Herrebrøden, 2023; Stambaugh, 2017, 2019). In contrast, an internal focus in sports, usually referring to isolated body parts, can disrupt coordination and automaticity (Montero et al., 2018). Previous studies also documented mixed findings for the FOA effect in music performance (Hohagen & Immerz, 2024).

Additionally, while it is generally argued that FOA effects depend on expertise (Masters & Maxwell, 2008; Tang et al., 2023), in our study neither participants' guitar experience nor their Type I expertise (performance on the metacognitive task) modulated FOA effects. This finding aligns with studies that have not demonstrated a consistent effect of expertise in music (Atkins, 2017; Atkins & Duke, 2013; Stambaugh, 2017, 2019).

Our findings align with broader concerns about FOA effects generalizability. A recent meta-analysis suggested publication bias may have overstated the benefits of an external focus (McKay et al., 2024). Moreover, the internal-external dichotomy may oversimplify attentional strategies, which are multidimensional and dynamic in real-world contexts. In both sports and music, performers continuously shift attention as task demands change, with internal and external foci co-occurring (Bahmani et al., 2019; Bernier et al., 2016).

No Evidence of a Metacognitive Mechanism for FOA effects

Although FOA did not affect overall performance, we observed within-subject variability for the FOA effects, motivating an examination of metacognitive monitoring as a modulating factor. We found strong evidence that metacognitive ability neither interacted with FOA nor influenced music performance. The lack of a significant association between metacognitive efficiency and motor performance contrasts with findings by Maurer et al. (2022). In their study, participants with easier conscious access to internal motor signals made more accurate predictions and maintained stable ball-throwing performance, while those with poorer access showed reduced prediction accuracy and ball-throwing execution. This discrepancy may reflect differences in the types of metacognitive processes engaged. According to the dual-systems model (Shea et al., 2014), metacognition can be fast and automatic (System 1) or slower and deliberative (System 2). Maurer et al.'s (2022) task likely required first-order outcome predictions rather than reflective processes (Fleming & Daw, 2017). In contrast, our metacognitive task required confidence judgments integrating multiple sources of information (proprioceptive, visual and auditory), some of which were ambiguous, thereby engaging the more effortful cognitive control of System 2. Thus, the role of metacognitive efficiency may be different depending on the task requirement; likewise, metacognitive efficiency may still modulate the effects of FOA in tasks involving automatic processing (Shea et al., 2014).

Differences in Visual-Tonal Metacognitive Ability

Interestingly, participants showed higher metacognitive ability for proximal (visual) parameters than for distal (tonal) ones. Exploratory analyses suggest that reduced metacognitive efficiency in the tonal condition stems from misattribution errors: movements deviating from the intended semitone were more likely to be attributed to the manipulation rather than the participant's own action in the tonal than the visual condition. While similar effects of intention were previously documented (Charalampaki et al., 2023), our results indicate that the effects may differ across domains. In pitch perception, small deviations may have been salient, making "out-of-pitch" outcomes more likely perceived negatively and attributed externally. By contrast, the broader range of acceptable error in the visual (fretboard) domain, possibly reduced misattribution. This effect is probably more influenced by expectations around guitar playing than by inherent sensory modality differences or stimulus properties. This account is consistent with evidence that negative or unintended outcomes can reduce the sense of agency (Yoshie & Haggard, 2013). Our findings may also reflect, speculatively, a form of intentional binding (perceived outcomes drawn closer to one's actions) in the perceptual (tonal) rather than the temporal domain, which is typically studied (Haggard et al., 2002). We emphasize that this is one possible explanation among several and may not capture all factors contributing to the observed effects.

Alternatively, these differences could indicate variation in the mechanisms underlying metacognitive monitoring across domains. While seemingly at odds with prominent outcome-based motor control theories (Hommel, 2013; Wohlschläger et al., 2003), Pfister's (2019) distinction between body and environment-related action effects offers an alternative perspective. Because visual feedback is more habitual and proximal to the body, it may be more informative for identifying the manipulation than indirect auditory feedback. Outcome-based control (arguably external), though still relevant, favors outcomes closely integrated with the motor system and immediate goals, which may explain superior performance in the visual condition. Exploratory analyses (in our Supplementary Material) comparing behavioral and self-reported metacognitive measures also hint at a dissociation between task-specific ("local") and broader ("global") metacognitive judgments, echoing recent findings (Double, 2025; Fleur et al., 2021; Terneusen et al., 2024) and supporting the notion of domain-specific metacognitive monitoring (Katyal & Fleming, 2024; Mazancieux et al., 2023; Rouault et al., 2018).

Limitations

Several important limitations should be noted. First, our music performance measure primarily focused on pitch and rhythm accuracy while overlooking expressive dimensions. While we still saw the effects of trial number on these measures, FOA and metacognitive efficiency may affect performance quality beyond pitch and rhythm accuracy. Second, our sample was largely amateurs and expertise was measured with a self-reported questionnaire, which may not accurately estimate skill level. Thus, the effects of FOA and metacognitive efficiency may differ in more experienced players. Third, our study relied solely on guitar, limiting generalizability to other instruments.

Conclusions

In sum, our findings call for reconsideration of the broad generalizability of the FOA effect across domains, showing no benefits in amateur (but experienced) guitarists. While we did not find evidence to support the hypothesis that metacognitive ability modulates the effects of FOA, our study nonetheless serves as an example of a paradigm to assess metacognition in the ecologically valid context of guitar playing.

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