Don't Break the Melody: Encouraging Accurate Handwriting Practice with Sound Feedback

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Abstract

In Japan, handwriting practice is an important part of education and often involves repeatedly writing the same character, which can become monotonous and reduce motivation. We propose a melody-based handwriting system that maps pen strokes to pitches and stops playback when the stroke leaves a predefined spatial gate, providing spatially-contingent auditory feedback that encourages accurate tracing while maintaining engagement. We implemented a browser-native, low-latency prototype that synchronizes visual input and audio in real time. In a controlled experiment comparing continuous feedback, restricted feedback (proposed), and no feedback, the proposed method led to slower, more attentive writing and a higher proportion of strokes within the designated range, indicating improved precision.

CCS Concepts

• **Human-centered computing → Sound-based input / output**.

Keywords

Handwriting Practice, Auditory Feedback, Handwriting Training System, Educational Technology, Stroke Trajectory

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1 Introduction

Even in today's digital era, where computers are ubiquitous, handwriting remains essential in various everyday contexts, such as signing contracts and filling out forms. According to a survey conducted by the Agency for Cultural Affairs in Japan, over 70% of respondents reported that they still write by hand in their daily lives, and more than 90% believe that preserving the habit of handwriting is important [1].

In Japan, handwriting practice begins in elementary school and involves a variety of methods, such as copying characters into notebooks and reading them aloud. One of the most common strategies for memorizing characters is to write them repeatedly. While this repetitive practice can be effective, it also tends to become monotonous. Consequently, survey evidence suggests that as pupils reach the upper elementary grades, many come to view repetitive kanji drills as tedious and report disliking kanji study [25].

To enhance motivation for handwriting practice, previous research has explored various methods, including approaches that amplify the sound of writing, which have been shown to support sustained engagement in handwriting tasks [18]. However, these methods typically focus on individual pen strokes and do not fully address the challenge of making handwriting practice more enjoyable as a whole.

To address this gap, we propose a handwriting practice system that generates melodies in real time based on pen trajectories. While this approach has the potential to make practice more engaging, if sound is played regardless of pen placement, users may focus more on producing sound than on accurate writing. To mitigate this, our system disables melody playback when a stroke leaves a predefined spatial gate from the reference character, encouraging more accurate tracing.

Before the main experiment, we conducted a pre-experiment to explore whether adding sound during practice could increase enjoyment and voluntary practice attempts. Results showed that, in the melody condition, participants who reported greater enjoyment tended to practice more. This finding motivated our adoption of a constrained playback design, in which sound continuity depends on both spatial accuracy and stroke order.

To evaluate the effectiveness of our proposed system, we conducted a controlled experiment comparing three auditory feedback conditions: continuous auditory feedback, restricted auditory feedback (i.e., our proposed method), and no auditory feedback. We analyzed changes in handwriting behavior, such as speed and accuracy, across these conditions.

Our contributions are as follows:

- **Melody-based handwriting practice system:** We proposed a handwriting practice system that maps pen strokes to melodies and mutes playback when deviations from reference strokes occur, providing spatially-contingent

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auditory feedback that encourages accurate tracing while maintaining enjoyment.

- **Empirical evaluation of feedback effects:** We conducted a controlled experiment comparing continuous, restricted, and no auditory feedback conditions, demonstrating that our method led to slower and more precise handwriting.
- **Implementation of a real-time multimodal prototype:** We implemented a browser-native, low-latency system that synchronizes visual input and auditory feedback in real time, demonstrating the practical integration of multimodal media technologies.

2 Related Work

2.1 Studies on handwriting practice support

Handwriting practice has been supported via automated error detection, social-robot tutoring, and instrumented pens for screening and assessment [5, 6]. A multimodal platform that pairs a tablet with a social robot lowers the barrier for teachers and therapists by embedding game-like practice with tailored guidance [28]. Automated Chinese handwriting checkers detect stroke-level errors and return immediate feedback at scale [17]. Pen-based tools that speak compositional hints during writing promote active recall and can even outperform visual-only guidance in retention [22]. Low-cost sensing of grip patterns has also been proposed for screening disorders [24]. Kubota et al. likewise explored motivation by visually merging user and model strokes to produce a single beautified trajectory during tracing [20]. Xu et al. developed VisDev, which visualizes stroke deviations via point-set registration for retrospective visual feedback [30]. These systems often provide continuous or discrete cues, yet they rarely make feedback continuity contingent on both spatial accuracy and stroke order, which is the gap our design targets.

Integrating sound into handwriting has been explored through acoustic pens, audio–haptic realism, and voice-guided instruction for BLV users [9]. Acoustic pens convert pen motion to pitch in real time [21], and combining visual and auditory cues can improve line accuracy on tablets [2]. LightWrite teaches letters to blind users using voice and haptics [29], while augmented styli enhance realism by simulating frictional sounds [8]. Sonic feedback has also supported early letter learning [15]. These prior works emphasize continuous or informative audio; in contrast, our system uses silence to signal spatial or sequential errors.

2.2 Behavioral Sonification and Multimodal Learning Effects

Event-triggered and adaptive sonification techniques have been widely applied in domains such as anomaly detection, motor learning, and rehabilitation. These approaches either play sound when a metric crosses a threshold or adapt parameters in real time based on user performance [3, 4, 11, 12, 16]. For example, SoNSTAR improves situational awareness by sonifying network traffic only when specific features exceed preset bounds [10], and wearable devices for postural training emit salient tones when users exceed safe rotation angles, improving recovery [13].

In the context of motor skill learning, sound mappings can be continuously adapted to optimize user performance. For instance, wearable gait sonification systems adjust feedback in real time [23], and Tai Chi training systems co-adapt audiovisual parameters based on pose errors to support learning [7]. These studies show how event-based and adaptive sonification can support behavior change.

Complementing these efforts, reviews on augmented feedback suggest that combining visual, auditory, and haptic cues improves retention and transfer of motor skills more than single-modality feedback [26]. Controlled studies with adolescents also show that the rate of concurrent auditory feedback affects postural control strategies at 24-hour retention tests [27]. These findings emphasize the need for post-tests and transfer tasks when evaluating multimodal feedback systems.

Our system draws inspiration from both sonification strategies and multimodal learning research. While our current study focuses on short-term effects such as increased attention and slower handwriting, we plan to extend our evaluation by adding post-test similarity metrics and long-term retention assessments. Moreover, we propose a novel "dual gating" mechanism that combines spatial deviation and stroke order constraints, making it well suited for handwriting practice.

3 Proposed Method

3.1 Interaction Design

Repetitive practice in character learning becomes tedious, reducing learners' motivation. Therefore, making handwriting practice enjoyable is essential for sustaining motivation. Furthermore, it is important not only to focus on each individual stroke but also to pay attention to the differences between characters.

This study aims to enhance handwriting practice by controlling how melodies are played, encouraging users to write more carefully. To achieve this, we designed the system so that sound will stop playing if the user's handwriting stroke deviates from the model stroke during tracing practice. By restricting the area where melodies can be triggered, we aim to encourage users to trace more accurately in order to maintain uninterrupted playback. We also expect this to promote more deliberate tracing of the model characters, which may result in slower writing speed. Furthermore, by restricting the valid range for melody playback, we expect the Euclidean distance between the model and user strokes to decrease.

3.2 Melody Feedback Design

3.2.1 Scale Selection and Pitch Mapping. Various features of handwriting, such as stroke length, speed, pressure, tilt, and curvature, can be used to generate sound. In this study, we aimed for consistency and intuitive interpretation by ensuring that writing the same character would always produce the same melody. To achieve this, we adopted a fixed pitch-mapping strategy based on the major pentatonic scale (Figure 1).

When writing the alphabet "A," for example, the melody transitions as follows: "Low E - Low D - High D," "Low E - Low G - High G," and "High D - High E - High G." We selected the major pentatonic scale for two main reasons: (1) to ensure pleasant-sounding melodies regardless of stroke direction [14], and (2) to minimize cognitive load. We limited the tone set to five notes to accommodate the irregular directions of handwriting movements and avoid dissonant sequences. Prior work has shown that simple

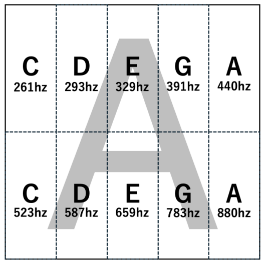

Figure 1: Diagram of melody scale mapping.

rhythmic regularity improves temporal predictability and reduces cognitive burden [19].

To implement this, pen coordinates (x, y) on the canvas are quantized to a coarse grid and converted into an additive index $i = i_x + i_y$. The oscillator frequency is then set to the ith pitch in the major pentatonic scale within a C4 to A5 range: {C4, D4, E4, G4, A4, C5, D5, E5, G5, A5}. This character-consistent mapping ensures pleasant consonance and predictable pitch transitions.

3.2.2 Temporal Behavior and Event Scheduling. Auditory feedback is driven entirely by user handwriting dynamics, without any external metronome or background harmony. On each pointer event, the system updates the oscillator frequency according to pen position and continues playback only while all gating conditions are met. Note onsets, offsets, and perceived rhythm emerge naturally from the user's motion, keeping the feedback tightly synchronized with the handwriting process.

3.3 Feedback Gating Design

3.3.1 Gating Logic and Stroke Order Control. Sound playback is governed by a dual gating mechanism that ensures feedback is contingent on both spatial accuracy and stroke sequencing.

- **Spatial Gate**: The distance from the pen point to the nearest reference stroke must stay below 20 px (Figures 2 and 3).
- **Stroke Order Gate**: The active stroke must match the expected sequence defined by the model character.

If either condition is violated, playback is immediately muted. For example, in the letter "A," if the cross-stroke is drawn before the left vertical stroke, the system produces no sound.

This dual gating design reinforces spatial and temporal correctness, encouraging users to trace more carefully in order to sustain melodic feedback.

3.3.2 Implementation Details and Parameters. The tracing sound is synthesized using the Web Audio API's `OscillatorNode` with a sawtooth waveform. The oscillator frequency is updated on every pointer event to ensure responsiveness, and playback is muted as soon as any gating condition fails. Key parameters are as follows:

- **Scale**: Major pentatonic scale from C4 to A5.
- **Spatial Gate**: 20 px based on the nearest neighbor distance to the reference stroke.
- **Mapping**: Grid quantization using additive index $i = i_x + i_y$.
- **Waveform**: Sawtooth waveform for tracing tone.
- **Timing**: No external rhythm; all timing is driven by user movement.

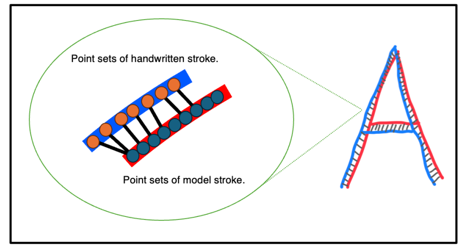

Figure 2: Illustration of how the Euclidean distance is calculated for each point in the handwritten stroke.

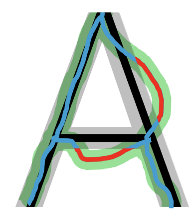

Figure 3: Reference character shown on screen (light gray) with its centerline for gating (black). Participant trace (green); its centerline sounds in blue and is silent in red. Drawing the crossbar before the left vertical closes the stroke-order gate.

This design ensures that feedback is strictly tied to handwriting accuracy and stroke order, while still providing engaging and informative melodic cues.

4 Pre-Experiment: Effect of Sound on Enjoyment and Practice Attempts

We conducted a pre-experiment to examine whether presenting sound during handwriting practice is associated with higher enjoyment and increased practice attempts. Participants practiced unfamiliar characters on a tablet with a stylus using our browser-based prototype under one of two conditions: melody

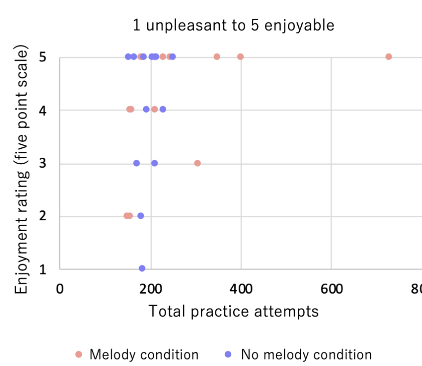

Figure 4: Relationship between total practice attempts and enjoyment in the pre-experiment. Each point represents one participant. Red = melody condition, Blue = no melody condition.

(unrestricted) or no melody ($N = 26$; melody $n = 13$, no melody $n = 13$). They practiced a fixed set of 16 Sanskrit characters over three days. Participants were instructed to complete at least three repetitions per day for each character and could add extra practice at will, yielding a minimum of 144 practice attempts per person ($16\ characters \times 3\ repetitions \times 3\ days$).

We recorded the total number of practice attempts and collected a single-item enjoyment rating on a 5-point Likert scale (1 = unpleasant, 5 = enjoyable). As shown in Figure 4, mean enjoyment ratings were 4.2 for the melody condition and 4.0 for the no melody condition. In the melody condition (red points), higher enjoyment ratings were associated with more practice attempts, whereas this pattern was not apparent in the no melody condition (blue points).

As the protocol differed from the controlled experiment, these results are descriptive and were used only to motivate the design of our main system. Based on this observation, our main system constrains playback so that sound continuity depends on both spatial accuracy and stroke order.

5 Experiment

5.1 Overview

This experiment tested the hypothesis that "restricting sound playback when the handwritten stroke exits the spatial gate around the model stroke encourages more careful tracing than when sound is played continuously."

Participants were divided into three groups based on the type of auditory feedback provided:

- **Baseline group**: No sound playback.
- **Sound group**: Continuous sound playback, regardless of pen position.
- **Restricted sound group (proposed method)**: Sound muted when the stroke exited the spatial gate around the reference stroke.

To investigate whether restricting the melody playback range affects writing speed and accuracy, the experiment used unfamiliar characters that participants had not practiced before. We selected 16 Sanskrit characters for this purpose, as they are not commonly encountered by Japanese participants. All participants confirmed they had no prior experience writing Sanskrit, ensuring that they approached the task without pre-existing knowledge or memorized stroke orders.

The experiment was conducted using an iPad Pro, Apple Pencil, and noise-cancelling headphones.

5.2 Experimental Procedures

Using the interface shown in Figure 5, participants practiced the 16 Sanskrit characters (Figure 6) five times each, using the assigned feedback condition. After a 5-minute break, all participants performed a test without auditory feedback or tracing models. This test was announced in advance to ensure participants were aware of the evaluation format.

During the test, the 16 characters were presented in random order on the left side of the screen, and a blank canvas for handwriting input was displayed on the right. Participants were instructed to write the characters from memory without any guidance on stroke order or sound feedback. To account for natural variation, each character was written three times. A smaller reference image was shown adjacent to the canvas to aid recall, but no stroke path was shown. This setup allowed us to assess both memory-based reproduction and spontaneous stroke sequencing under silent conditions.

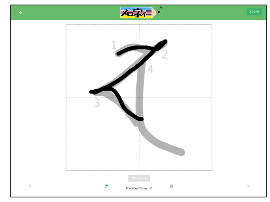

Figure 5: Character practice screen in the system used on an iPad.

Figure 6: Sixteen Sanskrit characters used in the experiment.

After completing the writing task, participants responded to an open-ended questionnaire about what they were consciously paying attention to while writing.

A total of 36 Japanese undergraduate and graduate students (32 male, 4 female) participated, with 12 assigned to each of the three groups. Each participant wrote 16 characters five times in the practice session and three times in the test session, for a theoretical total of 128 characters per person. Due to occasional network issues, some entries were lost, and the final dataset included 4,320 valid samples.

5.3 Evaluation Metrics

To investigate the effect of different auditory feedback methods on tracing speed, we analyzed the differences in tracing time among the sound group, the restricted sound group, and the baseline group. The restricted sound group used the proposed method in which sound playback was disabled when the stroke deviated from the reference. Additionally, we examined the impact on Euclidean distance between the participants' written characters and the model characters. Furthermore, we analyzed the test results conducted across all groups to evaluate the effectiveness of each method.

6 Results

To examine whether the three types of auditory feedback influenced handwriting speed, we analyzed the time required to trace each character. Figure 7 presents a box plot illustrating the time per pixel for each group. The vertical axis indicates the time (in milliseconds)

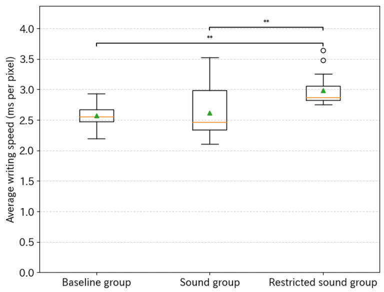

Figure 7: Time per pixel (ms) for each group.

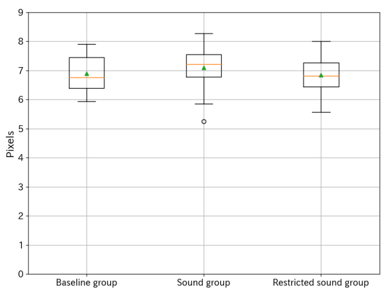

Figure 8: Mean Euclidean distance by group.

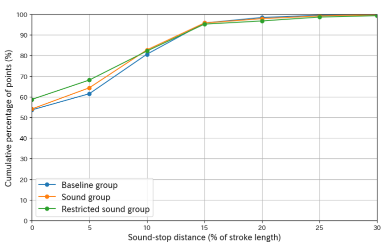

Figure 9: Cumulative distribution plot showing the percentage of stroke length where audio playback stopped (x-axis) versus the cumulative percentage of points within the spatial gate (y-axis), comparing three conditions.

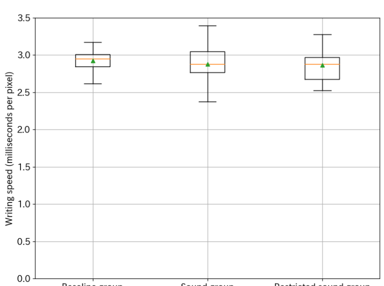

Figure 10: Time per pixel in the test (ms).

required to draw one pixel of a character. Since the number of data points varied for each type of character, we averaged the data for each character by method. The results indicate that there was no significant difference in tracing speed between the baseline group and the sound group, while the tracing speed was slower in the restricted sound group compared to the other two groups.

An analysis of variance (ANOVA) revealed a statistically significant difference in writing speeds among the groups ($F(2, 45) = 8.86$, $p < 0.001$, $\eta_p^2 = 0.28$). A post-hoc Tukey's HSD test showed significant differences between the Restricted group and both the Baseline ($p = 0.001$) and Sound groups ($p = 0.0042$), but not between the Baseline and Sound groups ($p = 0.88$). The effect sizes were large: Cohen's $d = 1.84$ (Restricted vs. Baseline, 95% CI: [1.38, 2.62]) and $d = 1.04$ (Restricted vs. Sound, 95% CI: [0.36, 2.14]). These results suggest that the restricted auditory feedback effectively encouraged slower and more deliberate handwriting behavior.

Next, to evaluate the deviation between the model characters and the traced handwriting, we calculated the Euclidean distance over the five practice attempts. The distance from the model character was defined as the average, for each character, of the minimum distances between each point in the handwritten stroke and the nearest point on the model stroke. In addition, the strokes were aligned according to their stroke order so that distances were measured between corresponding strokes. Since the number of points in a handwritten stroke varies with writing speed, a downsampling process was applied to ensure that the spacing between points was at least one pixel, thereby preventing variations in point density from affecting the analysis.

Figure 8 presents the results of the Euclidean distances between the traced strokes and the model characters for each group. The vertical axis represents the average Euclidean distance in pixels. The average distances were 6.76 pixels (baseline), 7.22 pixels (sound), and 6.82 pixels (restricted sound), but these differences were not statistically significant.

In the restricted condition, sound was disabled when strokes deviated more than 20 pixels from the model. Therefore, it is expected that the restricted sound group would have a higher proportion of points within this 20-pixel spatial gate compared to the other groups. Figure 9 presents a cumulative distribution graph showing, for each method and character type, the proportion of handwritten stroke points that deviated more than 20 pixels from the model. To account for differences in number of data across characters, downsampling was applied. The horizontal axis represents the proportion of points in a handwritten character that deviated more than 20 pixels from the model, while the vertical axis represents the cumulative proportion of characters. The results indicate that, for deviations below 0.05, the restricted sound group had the highest proportion of points within the 20-pixel spatial gate, while beyond this point there is almost no difference between the groups.

To examine whether differences in auditory feedback during practice affected writing speed in a test without sound feedback, we conducted a test in which participants wrote each presented character three times. Figure 10 presents a box plot illustrating the time per pixel during the test for each group. The median and mean times were 2.92 ms and 2.95 ms (baseline), 2.88 ms and 2.88 ms (sound), and 2.87 ms and 2.88 ms (restricted sound). The results indicate that there were no significant differences in writing speed among the groups.

7 Discussion

7.1 Summary and Interpretation

The experiment showed that participants in the *restricted sound* group traced more slowly than those in the other groups. This slowdown likely reflects greater attentiveness, as participants attempted to avoid breaking the melody. This supports our hypothesis that spatially-contingent auditory feedback encourages more deliberate handwriting.

Interestingly, the *sound* group exhibited the widest variance in tracing speed. Several participants noted they tried to match their stroke speed to the melody, suggesting that continuous audio may affect pacing strategies. By contrast, the *baseline* group showed more stable speeds, likely due to the absence of external cues.

Although differences in Euclidean distance were not statistically significant, the restricted group showed a higher within-gate proportion during practice; we treat this as descriptive evidence only. Adapting the spatial and stroke-order gating to user skill could yield additional benefits.

7.2 Post-Test Performance

To examine whether practice conditions influenced handwriting behavior in the absence of sound, a silent post-test was conducted. Participants wrote each of the 16 characters three times without auditory feedback or tracing guides. As shown in Figure 10, there were no statistically significant differences in time per pixel among the three groups during the test phase.

One-way ANOVA on test writing speed yielded non-significant results ($F(2, 2709) = 1.02$, $p = 0.361$), and pairwise t-tests also found no significant differences (Baseline vs. Sound: $t(1805.5) = 0.253$, $p = 0.800$, $d = 0.012$; Sound vs. Restricted: $t(1799.1) = 1.089$, $p = 0.276$, $d = 0.051$). However, the comparison between Baseline and Restricted groups showed a slightly positive point estimate for faster writing in the Restricted condition (Cohen's $d = 0.062$). This may indicate partial carry-over effects, though the magnitude was insufficient to reach significance.

The lack of auditory feedback in the test may have restored participants' habitual writing pace, reducing prior-condition differences. Because the size of handwritten characters varied among participants, similarity analysis was not possible, and future work will use normalized spatial metrics to assess retention and fidelity. The limited five practice trials per character may also have hindered transfer effects.

7.3 Participant Feedback

Open-ended responses revealed that 13 out of 36 participants reported consciously focusing on stroke order during practice. This is likely due to the presence of stroke guides on the interface and the advance notice of a test. Interestingly, one participant from the sound group and another from the restricted sound group reported that they mentally recalled the melody during the test phase, despite no auditory feedback being provided. While anecdotal, such responses suggest that auditory-based practice may facilitate internalization of stroke sequences and aid memory retrieval during handwriting tasks. This observation aligns with prior findings in other motor learning domains, where auditory feedback supports mental rehearsal.

In addition, participants' feedback hints at practical applications beyond user experience. For instance, we envision that teachers or parents could potentially infer a learner's level of engagement simply by listening to the playback pattern, enabling remote or passive supervision during handwriting practice sessions. Future studies may investigate whether auditory cues reliably reflect attention and accuracy.

7.4 Limitations and Future Work

This study has several limitations. First, the abrupt cessation of sound when a stroke exits the spatial gate may feel jarring and distract users. Second, the fixed 20-pixel gate was heuristically set and may not suit all ages or skill levels. Third, the five practice trials per character may have been insufficient to reveal long-term learning effects. Fourth, the sample comprised only Japanese university students, limiting generalizability across age groups and cultures. Finally, post-training retention or transfer evaluations were not conducted.

Future work will address these issues by implementing smoother audio transitions, such as fade-outs or amplitude envelopes, to improve feedback continuity. We also plan to develop adaptive gating mechanisms that adjust the spatial tolerance in real time based on user performance. Additional studies will include retention and transfer tests to assess learning outcomes over time. Furthermore, we aim to deploy the system in classroom environments, including Kanji practice for Japanese elementary students and non-native learners. We will also conduct studies with participants in other countries to test cross linguistic and cross script generalizability. Finally, we will explore whether auditory feedback patterns can serve as indicators of user engagement, supporting at-a-distance supervision by teachers or parents.

8 Conclusion

This study proposed a handwriting practice system that generates melodies from pen trajectories in real time, implemented as a browser-native, low-latency prototype that synchronizes visual and auditory feedback. Sound playback stops when a stroke leaves the spatial gate around the model, encouraging accurate tracing through spatially-contingent auditory feedback.

An experiment using unfamiliar Sanskrit characters showed that participants using the proposed system wrote more slowly and more carefully than those in the comparison groups. While no significant differences in test-phase writing speed were observed, a higher proportion of strokes in the restricted sound group remained within 20 pixels of the reference strokes, suggesting better adherence. These results demonstrate the potential of the proposed auditory feedback mechanism to support careful and engaged handwriting practice.

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References

[1] Agency for Cultural Affairs, Government of Japan. [n. d.]. https://www.bunka.go.jp/tokei_hakusho_shuppan/tokeichosa/kokugo_yoronchosa/pdf/h26_chosa_kekka.pdf. last accessed: 2025-3-11.

[2] Tue Haste Andersen and Shumin Zhai. 2010. Writing with Music: exploring the use of auditory feedback in gesture interface. *ACM Transactions on Applied Perception* 7, 3, Article 17 (2010).

[3] Gerold Baier, Thomas Hermann, and Ulrich Stephani. 2007. Event-based sonification of EEG rhythms in real time. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology* 118 (06 2007), 1377–86. doi:10.1016/j.clinph.2007.01.025

[4] Michael Barkasi, Ambika Bansal, Björn Jörges, and Laurence Harris. 2024. Online reach adjustments induced by real-time movement sonification. *Human Movement Science* 96 (07 2024), 103250. doi:10.1016/j.humov.2024.103250

[5] Rachel Bartov, Michael Wagner, Nir Shvalb, and Michal Hochhauser. 2023. Enhancing Handwriting Performance of Children with Developmental Coordination Disorder (DCD) Using Computerized Visual Feedback. *Children* 10, 9 (2023). doi:10.3390/children10091534

[6] Mugdim Bublin, Franz Werner, Andrea Kerschbaumer, Gernot Korak, Sebastian Geyer, Lena Rettinger, Erna Schönthaler, and Matthias Schmid-Kietreiber. 2023. Handwriting Evaluation Using Deep Learning with SensoGrip. *Sensors* 23, 11 (2023). doi:10.3390/s23115215

[7] Doga Cavdir, Chris Clarke, Patrick Chiu, Laurent Denoue, and Don Kimber. 2021. Reactive Video: Movement Sonification for Learning Physical Activity with Adaptive Video Playback. In *NIME 2021*. https://nime.pubpub.org/pub/dzlsifz6.

[8] Youngjun Cho, Andrea Bianchi, Nicolai Marquardt, and Nadia Bianchi-Berthouze. 2016. RealPen: Providing Realism in Handwriting Tasks on Touch Surfaces using Auditory-Tactile Feedback. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. 195–205.

[9] Jérémy Danna and Jean-Luc Velay. 2015. Basic and supplementary sensory feedback in handwriting. *Frontiers in Psychology* Volume 6 - 2015 (2015). doi:10.3389/fpsyg.2015.00169

[10] Mohamed Debashi and Paul Vickers. 2018. Sonification of network traffic flow for monitoring and situational awareness. *PLOS ONE* 13, 4 (04 2018), 1–31. doi:10.1371/journal.pone.0195948

[11] Gaël Dubus and Roberto Bresin. 2013. A Systematic Review of Mapping Strategies for the Sonification of Physical Quantities. *PLOS ONE* 8, 12 (12 2013), 1–28. doi:10.1371/journal.pone.0082491

[12] John F. Dyer, Paul Stapleton, and Matthew Rodger. 2017. Mapping Sonification for Perception and Action in Motor Skill Learning. *Frontiers in Neuroscience* Volume 11 - 2017 (2017). doi:10.3389/fnins.2017.00463

[13] Frank Feltham, Thomas Connelly, Chi-Tsun Cheng, and Toh Yen Pang. 2024. A Wearable Sonification System to Improve Movement Awareness: A Feasibility Study. *Applied Sciences* 14, 2 (2024). doi:10.3390/app14020816

[14] Kamraan Z. Gill and Dale Purves. 2009. A Biological Rationale for Musical Scales. *PLoS ONE* 4, 12 (Dec. 2009), e8144. doi:10.1371/journal.pone.0008144

[15] Katharina Gross-Vogt. 2024. The letter day project - designing sonic interaction for learning letters *(AM '24)*. Association for Computing Machinery, 502–510.

[16] Tobias Hildebrandt, Thomas Hermann, and Stefanie Rinderle-Ma. 2016. Continuous sonification enhances adequacy of interactions in peripheral process monitoring. *Int. J. Hum.-Comput. Stud.* 95, C (Nov. 2016), 54–65. doi:10.1016/j.ijhcs.2016.06.002

[17] Zhihui Hu, Yun Xu, Liusheng Huang, and Howard Leung. 2009. A Chinese Handwriting Education System with Automatic Error Detection. *JSW* 4 (01 2009), 101–107.

[18] Junghyun Kim, Tomoko Hashida, Tomoko Ohtani, and Takeshi Naemura. 2012. Effects of auditory feedback for augmenting the act of writing. *AH'12:Proceedings of the 3rd Augmented Human International Conference* 13 (2012), 1–4.

[19] Carol Krumhansl. 2000. Rhythm and pitch in music cognition. *Psychological bulletin* 126 (02 2000), 159–79. doi:10.1037//0033-2909.126.1.159

[20] Natsumi Kubota, Shinjiro Niino, Satoshi Nakamura, and Masaaki Macky Suzuki. 2016. A sustainable practice method of hand-drawing by merging user's stroke and model's stroke. In *Proceedings of the 1st International Workshop on CoMics ANalysis, Processing and Understanding (MANPU '16)*. Association for Computing Machinery, New York, NY, USA, Article 10, 6 pages. doi:10.1145/3011549.3011559

[21] Kazuki Nakada, Makoto Kobayashi, Yasuyuki Murai, Iwao Sekita, and Hisayuki Tatsumi. 2018. A tablet-type acoustic digital pen that presents pen strokes with music tones. In *Proceedings of the 10th International Conference on Education Technology and Computers*. Association for Computing Machinery, 297–301.

[22] Kouyou Otsu and Tomoko Izumi. 2023. Interactive Handwriting Device for Enhancing Active Recollection of Character Forms by Voice Assistance for Chinese Character Learning. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23)*. 7 pages.

[23] Toh Pang, Thomas Connelly, Frank Feltham, Chi-Tsun Cheng, Azizur Rahman, Jeffrey Chan, Luke McCarney, and Katrina Neville. 2024. A Wearable Personalised Sonification and Biofeedback Device to Enhance Movement Awareness. *Sensors* 24 (07 2024), 4814. doi:10.3390/s24154814

[24] Ana Phelippeau, Wim Poignon, Adrien Husson, Clément Duhart, Marc Teyssier, and Joel Chevrier. 2023. A Low-Cost Grip Pen Sensing Tool to Detect Handwriting Disorders. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (CHI EA '23)*. 7 pages.

[25] Naomi Shimamura. 1989. *[Children's Kanji Learning: Results from a Questionnaire Survey]*. Technical Report Report 96. National Institute for Japanese Language and Linguistics (NINJAL), Tokyo, Japan. 133–172 pages. doi:10.15084/00001120 In Japanese. English title translated by the authors..

[26] Roland Sigrist, Georg Rauter, Robert Riener, and Peter Wolf. 2013. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review* 20, 1 (2013), 21–53. doi:10.3758/s13423-012-0333-8

[27] Sánchez-Tormo, Alexis, Marco-Ahulló, Adrià, Estevan, Isaac, Monfort-Torres, Gonzalo, and García-Massó, Xavier. 2020. Rate of concurrent augmented auditory feedback in postural control learning in adolescents. *Mov Sport Sci/Sci Mot* 109 (2020), 15–21. doi:10.1051/sm/2020003

[28] Daniel C. Tozadore, Soizic Gauthier, Barbara Bruno, Chenyang Wang, Jianling Zou, Lise Aubin, Dominique Archambault, Mohamed Chetouani, Pierre Dillenbourg, David Cohen, and Salvatore M. Anzalone. 2023. The iReCheck project: using tablets and robots for personalised handwriting practice. In *Companion Publication of the 25th International Conference on Multimodal Interaction (ICMI '23 Companion)*. Association for Computing Machinery, 297–301.

[29] Zihan Wu, Chun Yu, Xuhai Xu, Tong Wei, Tianyuan Zou, Ruolin Wang, and Yuanchun Shi. 2021. LightWrite: Teach Handwriting to The Visually Impaired with A Smartphone. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. 15 pages.

[30] Yuzheng Xu, Shigeo Yoshida, Atsushi Hashimoto, and Yoshitaka Ushiku. 2025. VisDev: A Stroke Deviation Visualization System Using Point-Set Registration for Handwriting Training. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '25)*. Association for Computing Machinery, New York, NY, USA, Article 574, 7 pages. doi:10.1145/3706599.3720049