INTERVAL PATTERNS FACILITATE SHORT-TERM MEMORY ENCODING OF AUDITORY PITCH SEQUENCES

NATHAN A. ZAK
University at Buffalo, State University of New York

DAVID TEMPERLEY
Eastman School of Music, University of Rochester

PETER Q. PFORDRESHER
University at Buffalo, State University of New York

THIS STUDY INVESTIGATED SHORT-TERM MEMORY recognition for melodies and the effect of patterns (repeated subsequences) within a melody. Participants ($n = 54$) completed a same/different task in which they listened to two consecutive melodies on each trial that could be identical or could differ by one pitch. Melodies could contain patterns based on pitch intervals or melodic contour or could have no pattern structure (i.e., no repeated subsequences). Recognition was most accurate for melodies with interval-based patterns, intermediate for melodies with contour-based patterns, and worst for the no-pattern condition. However, participants with no music training only exhibited a recognition advantage over unpatterned melodies for melodies with interval-based patterns. Across participants, music training was associated with improved recognition for patterned melodies (interval or contour), but not for unpatterned melodies. These findings imply that pattern structure facilitates encoding of melodies in short-term musical memory in a graded fashion, with music training leading to enhanced encoding of pattern structure.

Received: July 2, 2024, accepted May 2, 2025.

Key words: pattern recognition, melody memory, pitch patterns, short-term memory recognition, music training

MELODIES DIFFER IN THEIR MEMORABILITY, with some becoming catchy earworms while others quickly fade from memory. This variability leads to the question: what makes a melody easy to remember? We propose that melodies are memorable when they contain *patterns* of some kind. Following Jones (1974), we define a "pattern" as a sequence of segments (subsequences) that are linked by a predictable rule system. For instance, the number sequence 1-2-3-4-2-3-4-5-3-4-5-6 is made up of a recurring subsequence of 4 ascending numbers (starting with 1-2-3-4), where the number starting each subsequence is one greater than the previous subsequence (i.e., 1-2-3-4 is followed by 2-3-4-5). In music theory, the use of patterns is associated with musical motives and is sometimes called *parallelism* (Lerdahl & Jackendoff, 1983); this has been shown to enhance the learning of melodies and support memory retention (Deutsch, 1980).

An example of this kind of repetition is the four-note "Fate" motive of Beethoven's Symphony No. 5 (Figure 1). The motive features a rhythmic pattern (short-short-short-long) and an intervallic pattern (two repetitions of a pitch followed by a descending third), and recurs many times in the piece. Although patterning in some music may be difficult to perceive or even absent (e.g., John Cage's "4'33"), music more commonly contains some kind of perceptible repeated structure to form patterns. Pattern recognition is an inherent human behavior and recognizing auditory patterns helps facilitate the perception of music (Lora, 1979). Patterning may have a role in making a melody more recognizable. The present experiment aims to investigate how different types of pattern structures within a melody can lead to varying degrees of recognition.

A melody can be defined as a sequence of pitches that sound like they belong together (Tan et al., 2010). Melodies exemplify Gestalt principles of perception, where discrete tones merge into a unified whole, creating memorability as a woven-together tune. In music, auditory events are thought to be cognitively organized into groups as distinct and intuitive segments—based on pitch, rhythm, and other factors—across various hierarchical levels (Lerdahl & Jackendoff, 1983). These

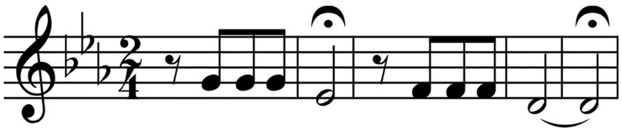

FIGURE 1. Beethoven's "Fate" motive (Symphony No. 5 in C minor).

Music Perception, VOLUME 43, ISSUE 4, PP. 358–368, ISSN 0730-7829, ELECTRONIC ISSN 1533-8312. DOI: https://doi.org/10.1525/MP.2025.2476514
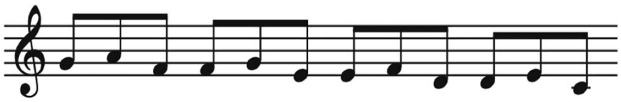
FIGURE 2. A pattern formed by a subsequence (+1, -2 steps) repeated in a larger 12-note sequence (-1 step descent at the start of each motive cell).

groups form the Gestalt organization that a listener may use in perception and memory encoding. Rather than a listener memorizing individual pitches (excluding skilled outliers with absolute pitch abilities), melodic sequences are thought to be collectively recognized through sets of inferred rules and heuristics (Deutsch, 1980). These principles guide how elements such as pitch, intervals, and harmony are processed as musical information. They also support the memory encoding of melodies, allowing them to be remembered as distinct groupings and patterns.

The presence of patterns may reduce the perceived complexity of melodies, impacting their memorability. A pattern, for instance, could be formed by a three-note subsequence that repeats four times at different pitch levels (Figure 2). Pitch sequences that repeat or are transformations of other sequences may facilitate memory encoding through chunking (Deutsch & Feroe, 1981), supporting the role of pattern structure in encoding. Melodies lacking discernible patterns tend to be more complex, while sequences featuring repetitive patterns are easier to encode. Patterns may facilitate memory because listeners can use them to form coded sequences as chunks in short-term memory (STM), by compressing cognitive data (Chekaf et al., 2016, Norris & Kalm, 2021). Lack of variation (i.e., repetition) in patterns has been shown to be more favorable for serial recall in other auditory modalities, such as spoken digits (Hartley et al., 2016). Additionally, the presence of patterns facilitates statistical learning, which may contribute to the recognition of melodic patterns (Moldwin et al., 2017). Research suggests that patterns are encoded and stored as units in auditory memory, indicating the brain's ability to automatically recognize patterns within auditory information (Alain et al., 1994, Sabri et al., 2004). Through the presence of patterns, repetition creates a sense of predictability, enhancing the ability to process and recall musical information reliably. As a result, patterns enhance memorability, suggesting an important role for them in melody recognition.

Patterns may be based on a contour code or an interval code (Peretz & Morais, 1987). Melodic intervals are here defined as transitions between sequentially adjacent notes in pitch space, measured via steps on a diatonic scale (for example, an ascending major second and minor second are both +1). Change in melodic contour is encoded with respect to whether adjacent pitches form an ascending or descending direction, independent of how large or small the amount of change is. Contour changes can be denoted with a "+" (ascending), "-" (descending), or "0" (unison). Encoding of melodies may be influenced by more detailed interval patterns, or more coarse-grained contour patterns. Figure 3 illustrates how a single melody (shown also in Figure 2) can be encoded using either code type.

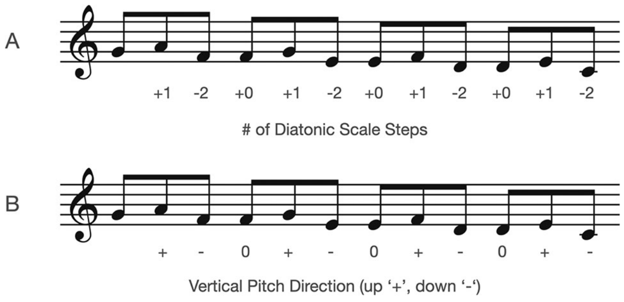

FIGURE 3. Melodic pattern types: (A) Melodic interval pattern coded by diatonic scale steps; (B) melodic contour pattern coded as up or down.

Deutsch and Feroe (1981) argued that listeners encode melodies based on an interval code and that memory for melodies therefore benefits from the presence of interval patterns. Empirical support for this view was reported in a study which found that structured interval information within sequences is particularly memorable (Deutsch, 1980). In this study, highly trained musicians performed a melodic dictation task (i.e., listening to melodies and then notating them immediately afterwards) with unfamiliar melodies that either featured recurring interval-based patterns or were unpatterned (i.e., melodies with no recurring subsequences). Results revealed better recall for melodies with interval patterns, suggesting that these patterns promote memory via chunking. The lack of a melodic pattern impaired participants' ability to notate melodies accurately. These results support Deutsch and Feroe's (1981) hierarchical model of encoding in which patterns of intervals assume a prominent role in melody recall. A further study by Acevedo et al. (2014), using a recognition paradigm, found that the recognition of melodies with interval patterns is enhanced when the metrical context supports the pattern (e.g., when a 4-note subsequence is paired with a binary meter, or a 3-note subsequence is paired with a ternary meter).

Some researchers have argued that contour information may be more fundamental to memory than interval information. For instance, Jones (1981) pointed out that interval-based codes used by Deutsch (1980) are vulnerable to an alternative account based on contour patterning. Subsequent empirical evidence suggested that melody memorability is influenced exclusively by melodic information serialized as contour pattern structure (Boltz & Jones, 1986). In an experiment similar to Deutsch (1980), trained musicians were tested with melodies containing contour alterations. Participants performed a similar melodic dictation task, where results indicated that repeated contour patterns were similarly sufficient for recall. This led to the conclusion that accent patterns, such as contour changes, play a prominent role in pattern retention in musicians' memory performance. An accent-based model was proposed, in which contour changes serve as melodic accents that draw the listener's attention and thus facilitate encoding. It has been suggested that contour may be processed independently of any musical scale influence (Dowling & Fujitani, 1971). Melodic contour has also been shown to be a primary feature in recognition of novel melodies after initial exposure, particularly after short durations (Dowling, 1978, Dowling & Bartlett, 1981). These results by Boltz and Jones and other views on contour imply that contour-based patterns also facilitate memory.

Pattern structure functions as a feature to facilitate melody memorability, with evidence of patterns of interval and contour affecting recall. However, the studies summarized above address only recall memory, in that dictation requires reproduction of the sequence held in memory, leaving open to question whether pattern structure plays a similar role in recognition memory. Another limitation of the dictation task is that it limits the possible sample to highly trained musicians, which curtails the interpretation to only a small population with unique skills. Acevedo et al.'s (2014) study, mentioned earlier, used a recognition paradigm and tested musicians and nonmusicians, but only employed interval-based patterns, not contour-based patterns or unpatterned melodies. The following experiment employed a recognition-based task to determine whether previous results generalize to a wider population background and to determine what types of pattern structures lead to higher memorability.

It is unclear based on previous correlational studies how differences in musical experience are associated with the role of pattern structure in memory encoding. People with no formal music education automatically process both contour and interval deviations in the auditory cortex with simple melodies (Trainor et al., 2002). However, the encoding of melodic information into memory can vary by musical experience (Bigand & Poulin-Charronnat, 2006; Tervaniemi et al., 2001). While musicians and nonmusicians tend to anticipate music similarly, research suggests that musicians versus nonmusicians may differ in memory recognition when processing specific musical stimuli (Kyrtsoudi et al., 2023). Generally, musicians show greater memory for tonal sequences than nonmusicians due to their training (Halpern & Bower, 1982). Music training is associated with advantages for working memory and processing speed (Saarikivi et al., 2019; Zuk et al., 2014). Acevedo et al. (2014) found differences in melody recognition based on participants' musical experience. Additionally, there is evidence using mismatch negativity data (MMN) that underlying neural mechanisms differ between musicians and nonmusicians when encoding interval and contour patterns, suggesting a difference in long-term memory processing of these specific melodic features (Fujioka et al., 2004). This MMN data suggests that music training enhances the encoding of melodic contour and interval structure as abstract melodic information. Overall, it is evident that musical background may significantly influence pattern recognition. For our experiment, we use an STM recognition task to explore the role of musical experience in the effects of pattern structure on melody encoding.

In our experimental design, we examined the role of interval patterns and contour patterns in making a melody recognizable shortly after its initial hearing. Like Acevedo et al. (2014), we use a recognition paradigm and employ signal detection measures. Signal detection is measured by dprime (d'), a measure of sensitivity, and functions to determine accuracy independent of response bias. Participants in the experiment listened to twelve-note melodies that varied with respect to pattern type: (1) interval patterns, (2) contour patterns, or (3) an unpatterned structure (the control condition). On each trial, participants heard a standard melody followed by a comparison that could be an exact repetition or could differ with respect to one pitch. Recognition accuracy was evaluated based on the participants' ability to identify whether the comparison melody was the same or different from the standard melody.

Method

PARTICIPANTS

The target sample size was informed by a power analysis based on the effect size associated with the main effect of pattern structure (binary versus ternary grouping of subsequences) from Acevedo et al. (2014). Although this manipulation was not the same manipulation of pattern structure as we use in the present study, the task in Acevedo et al. is identical to ours and the melodic stimuli in other respects were highly similar. Pattern structure in Experiment 1 of that study yielded a strong effect $\eta^2 = .54$. Based on the output of G-power, a total sample size of $n = 12$ would be necessary to detect a significant effect of a comparable size at a power of $1 - \beta = .95$. We used this estimate as the minimum number of participants to recruit representing nonmusicians (no music training) or musicians (at least 6 years of private instruction and currently practicing). This distinction was guided by a common categorization in music cognition designs (e.g., Zhang et al., 2020), separating nonmusicians as those with no music training, and musicians as those with six or more years of music training who are currently practicing.

Participants were recruited from three different populations. The first group was sampled from undergraduates in the Psychology Department at the University at Buffalo ($n = 34$), earning course credit for their participation. As there were not enough highly trained musicians in this group, we needed to sample more broadly. The second group was recruited via email from students enrolled in an introductory music theory course at the Eastman School of Music ($n = 4$), each compensated with a gift card for their time. After this recruitment, we needed to sample further to find more experienced musicians. The third group was sampled from a network of self-identified musicians around the greater Buffalo, New York, region ($n = 19$), recruited by flyers and word of mouth, each compensated for their time with a gift card. Participants were each screened for English proficiency for instructional understanding and reported no hearing loss.

The participants' musical backgrounds were measured using a questionnaire. Responses included the number of years of private (i.e., individual) music lessons, number of years playing an instrument, and current practice time in hours per week. Musical experience was categorized in four subgroups (Table 1): those with no music training ($n = 19$), one to five years of music training ($n = 17$), six or more years of music training but not currently practicing ($n = 7$), and six or more years of music training with current practice ($n = 15$). The musicians with six or more years of music training who were currently practicing averaged 11.5 years of private lessons over their lifetimes and were currently practicing an average of 8.6 hours per week. One participant from the third group reported having absolute pitch.

DESIGN AND CONDITIONS

The melodies used in the experiment were of three different types: intervallic pattern, contour pattern, and unpatterned. The intervallic and contour melodies consisted of "cells" of subsequences repeated in a larger pattern, as shown in Figure 4. Twelve melodies were composed for each pattern type, each comprising 12 notes. Half of the (patterned) twelve-note melodies consisted of three-note cells, and half consisted of four-note cells.

The interval pattern melodies were based on either a three-note or a four-note intervallic cell repeated in a larger intervallic pattern. For example, the melody in Figure 5A is based on the intervallic cell +2 +2 +1, embedded in a larger frame whereby each cell starts on a pitch one scale step higher than the starting pitch of the previous cell, creating a larger sequence over the 12-note duration.

The second type of pattern structure comprised patterns based on melodic contour. The contour patterns

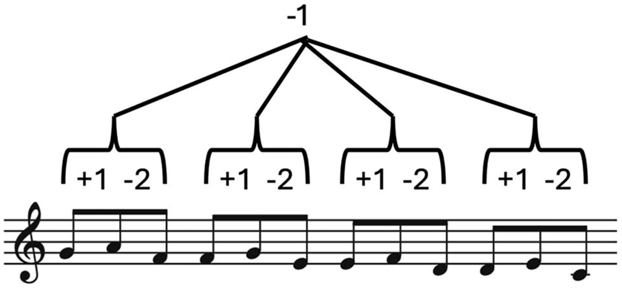

FIGURE 4. Brackets highlight 3-note "cells" within a 12-note sequence. The first note of each cell is one scale step lower than that of the previous cell, creating a hierarchical pattern in which the interval structure of each cell repeats (+1, -2 scale steps).

TABLE 1. *Demographics of Study Sample for Musical Background*

Group category	*N*	% Female	Age	Private Training (years)	Experience (years)	Current Practice (hours/week)
No music training	19	47	19.70 (2.10)	N/A	N/A	0.79[1] (2.51)
1–5 years music training	17	53	20.56 (3.12)	3.29 (1.53)	7.9 (5.61)	2.71 (6.55)
6 or more years, not currently active	7	57	21.28 (2.92)	9.43 (1.81)	11.7 (4.92)	N/A
6 or more years, currently active	15	47	27.6 (11.47)	11.8 (2.78)	17.7 (9.49)	8.6 (7.56)

Note. [1] One participant reported no music training but reported practicing 10 hours per week. Values are presented as mean (standard deviation).

are structured so that there are cells of directional motions (ascending or descending) contained in the melodies. Contour-pattern melodies contain a three-note or four-note contour cell repeated in a larger contour pattern. For example, the melody in Figure 5B is based on the contour cell "+ + +", with a descending interval separating each cell from the following one. Contour-pattern melodies were constructed to avoid full repetition of interval cells, similar to patterns used by Boltz and Jones (1986).

The third type of melody was deliberately designed to be "unpatterned," acting as a control, illustrated in Figure 5C. These melodies were created to minimize any repeated subsequences within them. The unpatterned melodies did not include any repetitions of three-note or four-note intervallic cells.

The composition of the melodies was restricted to C major scale tones, with pitches ranging from B3 to C5. Diatonic steps were used to measure intervallic patterns, rather than chromatic scale steps that would introduce tonally incongruent notes. The Deutsch and Feroe (1981) model proposes that diatonic steps are suitable when the "alphabet" determining the elements of a sequence is the diatonic scale. None of the melodic intervals exceeded a perfect fifth and melodic tritones (F-B) were avoided. Melodies started on various pitches but ended on C4 or C5. The properties of the melodic stimuli across all six conditions (three standard and three altered) are included in Table 2. The average number of distinct pitches used across the conditions was 6.2. The mean diatonic interval size remained constant ($M = 1.576$) across all conditions. The mean contour reversals were recorded, denoting the number of times a contour reverses direction in a melody. The pitch range was recorded as the average difference between the lowest and highest pitch. Tonality fit is a measure of how well the pitches fit in a tonal framework in the C major scale, with higher values indicating a better fit.
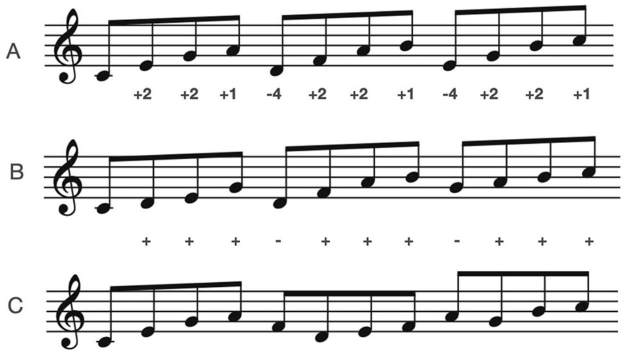
FIGURE 5. Examples of pattern types used as stimuli: (A) Patterns of intervals coded as steps; (B) patterns of contour coded as pitch direction; (C) unpatterned sequences as a control group. Unpatterned sequences were composed to minimize discernable patterns.

For every composed melody, we created an altered version that had a single pitch alteration relative to the standard melody (Figure 6). Note alterations (i.e., the new note in the altered melody) were placed in various locations within melodies that do not correspond to metrical accents (assuming that metrical accents are heard on the first note of each cell). Alterations in three-note melodies were always at position 5, 6, 8, or 9, and alterations in four-note melodies were always at position 4, 6, 8, or 10. These positions of change were equally distributed. The alteration was always a pitch that occurred somewhere else in the melody. The alterations of interval and contour pattern structure across the comparison melodies were produced in the same fashion. The alteration always led to a localized change in the melodic contour of the comparison melody, relative to the original melody. The mean interval size between the alteration and the corresponding standard note was the same across the three conditions: 3.17 scale steps. All participants experienced the same set of melodies and altered versions.

APPARATUS AND STIMULUS GENERATION

Melodic sequence stimuli were composed manually using the Finale music notation program and then converted into MP3 files using Finale's grand piano sound. This timbre was used throughout the experiment for the

TABLE 2. *Properties of Melodic Stimuli*

Condition	Unique Pitches (*N*)	Mean Diatonic Interval Size	Contour Reversals (*N*)	Pitch Range	Tonality Fit[1]
Interval	6.2	1.576	5.6	7	0.95
Contour	6.1	1.576	5.3	7.1	0.96
Unpatterned	6.3	1.576	6.2	7.1	0.95

Note. [1] Temperley-Kostka-Payne chord-based profile used for pitch class distribution in the key of C major.

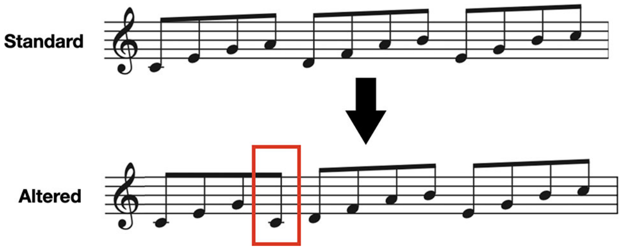

FIGURE 6. An example of a single note alteration in an altered melody relative to the standard melody. The single altered note changes the subsequence within the larger 12-note sequence.

melodic sequences. All notes were 0.25 seconds in duration and there was a gap of 0.75 seconds between each standard and comparison melody. The practice trial stimuli were created separate from the melodic sequence stimuli, using Apple Logic and the grand piano plug-in. A script on the behavioral science platform Finding Five (FindingFive Corporation) was created to run the experimental trials and collect the response data. The first group of participants completed the experiment in the Psychology Department at the University at Buffalo. Instructions for the on-site participants were presented via a Dell computer monitor in a sound attenuated booth with audio stimuli played through over-the-ear headphones (ANC Wireless Stereo Headphones). The second and third groups of participants that were available remotely from the Eastman School of Music and Buffalo, New York, were administered trials over a Zoom video call. The online participants were asked to provide headphones and conduct the call in a quiet, private location before the start of the task.

PROCEDURE

Participants began with instructions given through the computer monitor. The participants were presented with a screen that read "Two melodies will be played. Listen to them and answer 'yes' if they are the same melody, or 'no' if they are different." "Melody #1" then appeared on the screen, followed by "Melody #2"; the two consecutive melodies were either identical or differed by a single pitch. Participants indicated "yes" responses using the "F" key, or "no" responses using the "J" key. Each participant began with a practice trial to affirm that the task instructions were understood by using the familiar nursery rhyme melody *Twinkle, Twinkle Little Star* for ease of recognition. A total of 72 trials were completed: 24 trials for each of the three pattern types (50% same, 50% different).

The arrangement of the trials was generated by a randomized order and then edited. To ensure participant attention, catch trials featuring another familiar melody, *Mary Had a Little Lamb*, were placed 1/3 and 2/3 of the way through the experiment. All participants answered the catch trials correctly. Musical background information was surveyed through a Qualtrics questionnaire at the end of the trials. Each session lasted around 30 minutes.

DATA ANALYSIS

We conducted a within-subjects analysis of variance (ANOVA) with the single factor Pattern Type (interval, contour, or unpatterned), using the signal detection parameter d' (d prime) as a dependent variable. Standard corrections in the computation of d' were applied to individual hit rates and false-alarm rates at floor or ceiling as in Acevedo et al. (2014): the correction for ceiling values at 100% for either hits or false alarms was 1 – (1/2N) and the correction for floor values (0%) was 1 / (2N). For melody subsequence length effects, a *t*-test showed that the recognition accuracy did not differ across sequences with cells having note lengths of three versus four ($p = .96$). As cell length is not central to our predictions, we aggregated over this factor to enhance statistical power. Post hoc paired *t*-tests were used to compare different pattern types. All significant tests for pairwise contrasts were based on a Holm-Bonferroni correction. We analyzed by ANOVA the potential effect of music training on pattern recognition accuracy based on groups (using the two most extreme categories from Table 1) and additionally used years of private training as a comparative variable.

Results

The single-factor within-subjects ANOVA yielded a significant main effect of pattern type on d', $F(2, 106) = 24.89$, $p < .001$, $\eta^2 = .32$. As shown in Figure 7, d' was highest for recognition of melodies with interval patterns ($M = 1.410$, $SD = 0.788$), intermediate for melodies with contour patterns ($M = 0.980$, $SD = 0.624$), and lowest for unpatterned sequences ($M = 0.672$, $SD = 0.658$). Post hoc paired *t*-tests indicated that interval patterns yielded significantly higher d' sensitivity compared to both contour patterns, $t(53) = 4.46$, $p < .001$, $R^2 = .27$, and unpatterned sequences, $t(53) = 6.65$, $p < .001$, $R^2 = .46$. Contour patterns demonstrated significantly higher d' sensitivity than unpatterned sequences, $t(53) = 2.87$, $p = .006$, $R^2 = .14$. These findings confirm that pattern type significantly influenced the participants' recognition abilities. For all the "same" trials, a *t*-test shows a significant accuracy for interval patterns compared to contour patterns ($p < .001$), indicating that the effect of pattern type was present when participants perceived the original melody rather than alterations to it. The results provide evidence of higher sensitivity (d') for interval patterns compared to contour patterns and unpatterened sequences. The gradation of pattern type influence is evident, as contour patterns had a greater sensitivity (d') than unpatterened sequences.

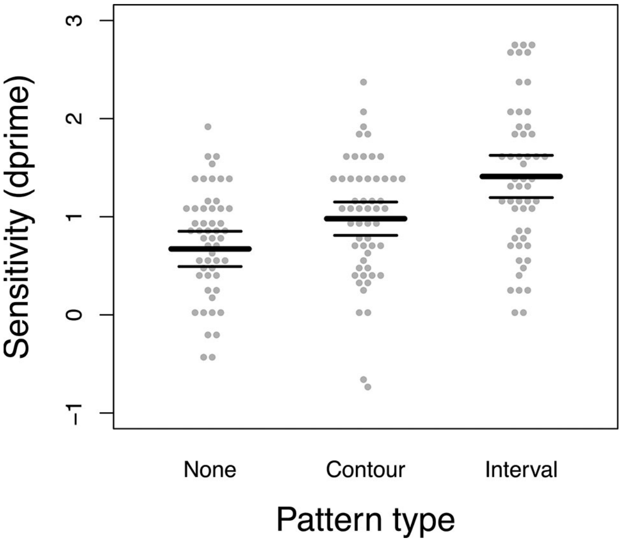

FIGURE 7. Swarm plots displaying d' by pattern type. The mean for each pattern type is denoted by a bold horizontal line surrounded by lighter horizontal lines displaying 95% confidence intervals, with each participant's d' plotted as grey dots.

Next, we addressed how musical experience influenced recognition performance. For those with no music training (Figure 8A, $n = 19$, see Table 1), there was a significant main effect of pattern type on d' sensitivity, $F(2, 36) = 4.48$, $p = .018$, $\eta^2 = .199$. However, unlike the entire sample, for this subset there was no advantage for melodies with contour-based patterns. Post hoc tests revealed that interval patterns showed significantly higher d' sensitivity than unpatterned sequences, $t(18) = 2.81$, $p = .011$, $R^2 = 0.31$, but there was no significant difference between contour and unpatterned sequences, $t(18) = 1.34$, $p = .23$, *ns*, $R^2 = .08$. By contrast, participants with at least six years of music training and who were currently practicing (Figure 8B, $n = 15$, see Table 1) yielded results similar to those for the entire sample. The ANOVA for this subset revealed a significant effect of pattern type on d' sensitivity, $F(2, 26) = 16.54$, $p < .001$, $\eta^2 = .56$, and post hoc comparisons revealed higher d' for interval than contour patterns, $t(13) = 3.16$, $p = .008$, and higher d' for interval patterns than unpatterned sequences $t(13) = 5.57$, $p < .001$. Notably, unlike participants with no music training, and similar to the entire sample, skilled musicians showed significantly higher d' sensitivity for contour patterns than unpatterned sequences, $t(13) = 2.59$, $p = .022$, $R^2 = .34$. The contrast between interval-based patterns and contour-based patterns was not significant for participants with no music training, $t(18) = 1.95$, $p = .067$, *ns*, $R^2 = .17$, but was significant for participants categorized as musically

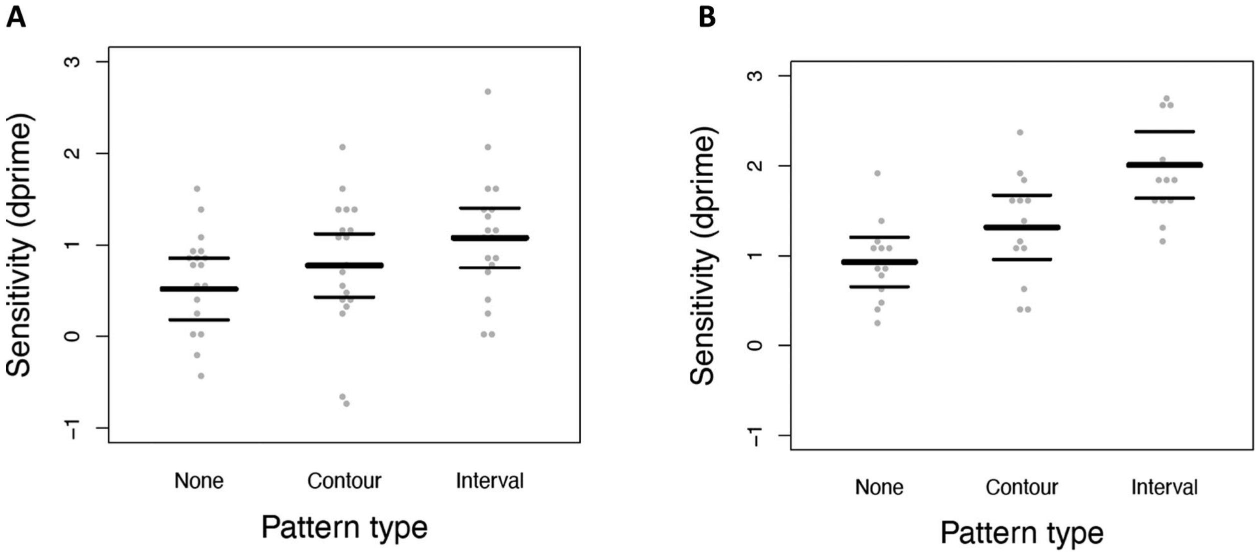

FIGURE 8. Swarm plots showing sensitivity, organized as in Fig. 7, plotted separately for (A) participants with no private music training ($n = 19$) and (B) musicians with six or more years of training with current practice ($n = 15$).

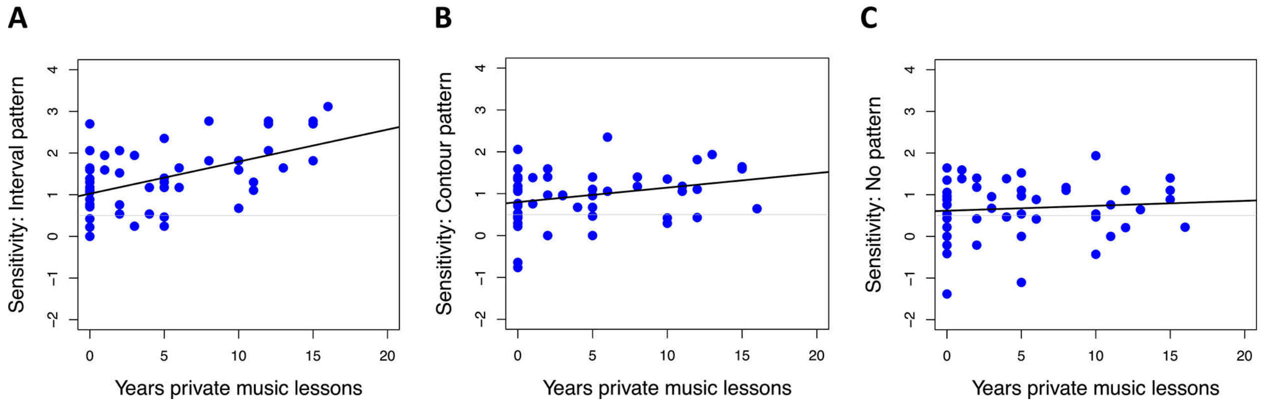

FIGURE 9. (A) Regression plot showing the relationship between years of private music lessons (*x*-axis) and accuracy (*y*-axis) for (A) interval pattern recognition, (B) contour pattern recognition, and (C) unpatterned sequence recognition. Dark black lines represent least-squares linear regression, and grey horizontal lines highlight chance performance.

experienced, $t(13) = 3.29$, $p = .006$, $R^2 = .45$. These findings suggest the effect that music training has on recognition accuracy, indicating that while contour patterns may not provide an advantage for those without music training, they do influence sensitivity levels in those with a higher degree of music training.

We next addressed the possibility that musical experience may be related to recognition performance on a continuum. We correlated sensitivity (d') with years of music training separately for each pattern type (Figure 9). Sensitivity for melodies with interval-based patterns (Figure 9A) was significantly correlated with music training, $r(52) = .53$, $p < .001$. Contour-based patterns (Figure 9B) also showed a significant, though smaller, correlation, $r(52) = .35$, $p = .013$. Music training was not significantly correlated with d' for unpatterned sequences (Figure 9C), $r(52) = .12$, $p = .188$, *ns*. We also compared the musician and nonmusician groups in a *t*-test for the unpatterned melodies; there was no significant difference in scores between nonmusicians ($M = 0.52$, $SD = 0.70$) and musicians ($M = 0.93$, $SD = 0.46$); $t(30) = -1.86$, $p = .072$, *ns*, $R^2 = .10$. Overall, these correlation analyses show that music training is associated with improved recognition, but only when pattern structure is present in melodic sequences.

Discussion

In addressing the original question, “Why are some tunes more immediately memorable than others?” our results suggest that different types of pitch patterns within a melodic sequence support the encoding of short-term musical memory. Interval-based pattern sequences provide the most effective structure for enhancing STM for melodies. For both musicians and nonmusicians, the presence of a repetitive interval pattern increases memorability. Musicians seem to be able to pick up on patterns based on contour even if there are not precise intervallic matches. These types of pattern structure were also shown to facilitate memory in a graded fashion with respect to how much music training one has. For unpatterned sequences, music training did not help facilitate STM recognition.

We measured recognition of auditory sequences in STM based on specific types of patterned subsequences. Participants were asked to discriminate between a pair of consecutively played melodic sequences with a potential single pitch alteration, reporting whether they were the same or different. Three types of melodies were used: interval-pattern, contour-pattern, and unpatterned. Specifically, recognition accuracy was highest for interval-pattern melodies, intermediate for contour-pattern melodies, and lowest for unpatterned melodies. Musical experience was associated with a graded effect: we found a positive correlation between years of music training and recognition performance for interval and contour-based patterns.

We aimed to test two competing theories in serial pattern research. The serial processing model proposed by Deutsch and Feroe (1981) and tested by Deutsch (1980) emphasizes the encoding of interval-based patterns that form hierarchical structures. This hierarchical model reflects the plausibility of intervallic subsequences as a salient pattern. Our findings show support for this model, indicating that interval-based patterns were more recognizable than contour-based patterns in our study. By contrast, the model of Boltz and Jones (1986) suggests that regularly timed contour accents may be sufficient to facilitate encoding, with no additional advantage for interval-based recursive hierarchies. Although contour patterning also facilitated recognition in the present data across the entire participant sample, interval patterning provided an additional boost to recognition ability. While the recognition of repeated interval patterns may be facilitated by their shared contour similarity, our study indicates that the facilitative effect of interval pattern repetition is not only due to contour similarity, since contour repetition alone (without interval repetition) has a less facilitative effect. Thus, our data suggest that contour structure increases memorability for musicians, but also that interval-pattern repetition has a role beyond this.

Lastly, we were able to assess a more diverse musical background within our population compared to these previous studies. These comparisons suggest that the benefit of contour is only present for trained musicians. This is surprising in light of previous results suggesting that musicians process contour information similarly to nonmusicians, whereas musicians exhibit enhanced processing of intervals relative to nonmusicians (Bigand & Poulin-Charronnat, 2006; Schubert & Stevens, 2006). Fujioka et al. (2004) demonstrated that music training enhances the automatic processing of contour and interval structure. In that study, musicians exhibited significantly larger magnetic mismatch negativity (MMN) responses to melodies with deviant interval and contours compared to nonmusicians. Musicians found interval information more memorable than contour information, as shown by the larger MMN responses to interval deviations. There are inherent limitations to the sample size used in our study for expert level musicians; however, our correlational analysis addressed this observed graded effect of music training on recognition.

Learned interval or contour patterns may aid the process of grouping in STM. Generally, grouping a sequence into smaller subsequences plays an important role in the ordering of serialized information in STM (Henson, 1998). STM actively incorporates learned regularities, and long-term learning effects have been associated with serial recall of information within STM (Majerus et al., 2012). Huron (2006) notes that music is uniquely repetitive compared to other auditory stimuli, and that musical patterns may help push short-term auditory sequences into a longer-term memory. Huron describes how music's inherent tendency for repetition can function as an "involuntary form of conscious memorization," and allow for conscious expectations to arise in working memory. Short-term melodic memory may respond differently due to long-term learning of melodic patterns, associated with years of music training. To explain auditory pattern recognition in a wider population without enhanced recognition abilities, listeners may form chunks in immediate memory before any long-term memory retrieval occurs, as noted by Chekaf et al., 2016. While individual differences in working memory ability may exist independent of music training (Berz, 1995), our results suggest that learned information through musical experience reinforces the retention of melodic stimuli. It is also possible that musicians, especially those trained as singers, may have enhanced retention for melodies in a recognition task through learned rehearsal strategies, such as subvocal singing (Pruitt et al., 2019).

Our results further indicate that music training does not facilitate recognition of unpatterned sequences. Unpatterned information in a melody may be less recognizable due to its lack of sequence structure. In verbal information retrieval, STM decays faster when a supporting syntactic structure is removed, indicating how recognition memory is supported by learned sequences (Schweppe et al., 2021). Our results also draw parallels to cognitive psychology experiments in which chess masters can quickly memorize the location of chess pieces based on positions that would occur in a match but show no advantage over novices when asked to recall randomly positioned pieces (Chase & Simon, 1973). Like chess masters, the present results indicate how musicians' encoding for recognition memory is supported by learned subsequences, rather than unpatterned information. The more effective recognition memory observed for musicians may be based on their ability to encode melodies based on patterned subsequences and not enhanced memory span for unpatterned pitch sequences.

While nearly all musical styles involve some kind of melodic pattern repetition, the kinds of repetition used may differ across styles. In classical music, repetition of intervallic patterns at different pitch levels (as in Figure 1) is extremely common; in popular music, it is much less so, with exact repetition of both intervals and pitches being the norm (Temperley, 2023). One might expect, then, that training in classical music would enhance sensitivity to intervallic patterns, but this was not assessed. Repetition of contour patterns would seem to be common in both classical and popular music, though there has been little discussion of this.

The melodies in our study were confined to a very limited space with regard to features such as melodic range, interval size, scale-degree (only diatonic scale-degrees were used), and rhythm. Exploring a wider variety of melodies could provide for a more comprehensive understanding of the observed effects. Another question is whether repeated intervallic cells enhance recognition when the repetition does not form a larger pattern (e.g., ascending by step), as it did in our experiment. Sensitivity to other kinds of scales or "alphabets"—chromatic scales, pentatonic scales, or chord-based patterns (arpeggios)—could also be explored. It would also be interesting to examine the effects of pattern repetition on melodic expectation—an issue that has received surprisingly little attention.

In conclusion, our results indicate how pattern structures may facilitate short-term memory encoding in a graded fashion. Interval-based patterns were shown to be more recognizable than contour-based patterns. The greater salience of interval over contour supports the Deutsch hierarchical model of serial pattern processing. Additionally, music training and experience lead to enhanced pattern recognition in the listener.

Author Note

Correspondence concerning this article should be addressed to Peter Pfordresher (pqp@buffalo.edu).

References

Acevedo, S., Temperley, D., & Pfordresher, P. Q. (2014). Effects of metrical encoding on melody recognition. *Music Perception*, *31*(4), 372–386.

Alain, C., Woods, D. L., and Ogawa, K. H. (1994). Brain indices of automatic pattern processing. *NeuroReport*, *6*(1),140–144.

Berz, W. L. (1995). Working memory in music: A theoretical model. *Music Perception*, *12*(3), 353–364.

Bigand, E., & Poulin-Charronnat, B. (2006). Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training. *Cognition*, *100*(1), 100–130.

Boltz, M. G., & Jones, M. R. (1986). Does rule recursion make melodies easier to reproduce? If not, what does? *Cognitive Psychology*, *18*(4), 389-431.

Chekaf, M., Cowan, N., & Mathy, F. (2016). Chunk formation in immediate memory and how it relates to data compression. *Cognition*, *155*, 96–107.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology 4*(1), 55–81.

Deutsch, D. (1980). The processing of structured and unstructured tonal sequences. *Perception and Psychophysics*, *28*(5), 381–389.

Deutsch, D., & Feroe, J. (1981). The internal representation of pitch sequences in tonal music. *Psychological Review*, *88*(6), 503–522.

Dowling, W. J. (1978). Scale and contour: Two components of a theory of memory for melodies. *Psychological Review*, *85*(4), 341–354.

Dowling, W. J., & Bartlett, J. C. (1981). The importance of interval information in long-term memory for melodies. *Psychomusicology*, *1*, 30–49.

Dowling, W. J., & Fujitani, D. S. (1971). Contour, interval, and pitch recognition in memory for melodies. *Journal of the Acoustical Society of America*, *49*(2, Pt. 2), 524–531.

Fujioka, T., Trainor, L. J., Ross, B., Kakigi, R., & Pantev, C. (2004). Musical training enhances automatic encoding of melodic contour and interval structure. *Journal of Cognitive Neuroscience*, *16*(6), 1010–1021.

Halpern, A. R., & Bower, G. H. (1982). Musical expertise and melodic structure in memory for musical notation. *The American Journal of Psychology*, *95*(1), 31–50.

Hartley, T., Hurlstone, M. J., & Hitch, G. J. (2016). Effects of rhythm on memory for spoken sequences: A model and tests of its stimulus-driven mechanism. *Cognitive Psychology*, *87*, 135–178.

Henson, R. N. A. (1998). Short-term memory for serial order: The start-end model. *Cognitive Psychology*, *36*(2), 73–137.

Huron, D. B. (2006). *Sweet anticipation: Music and the psychology of expectation*. MIT Press.

Jones, M. R. (1974). Cognitive representations of serial patterns. In B. Kantwoiz (Ed.), *Human information processing* (pp. 187–229). Lawrence Earlbaum.

Jones, M. R. (1981). A tutorial on some issues and methods in serial pattern research. *Perception and Psychophysics*, *30*(5), 492–504.

Kyrtsoudi, M., Sidiras, C., Papadelis, G., & Iliadou, V. M. (2023). Auditory processing in musicians, a cross-sectional study, as a basis for auditory training optimization. *Healthcare*, *11*(14), 2027.

Lerdahl, F., & Jackendoff, R. (1983). *A generative theory of tonal music*. MIT Press.

Lora, D. (1979). Musical pattern perception. *College Music Symposium*, *19*(1), 166–182.

Majerus, S., Martinez Perez, T., & Oberauer, K. (2012). Two distinct origins of long-term learning effects in verbal short-term memory. *Journal of Memory and Language*, *66*(1), 38–51.

Moldwin, T., Schwartz, O., & Sussman, E. S. (2017). Statistical learning of melodic patterns influences the brain's besponse to wrong notes. *Journal of Cognitive Neuroscience*, *29*(12), 2114–2122.

Norris, D., & Kalm, K. (2021). Chunking and data compression in verbal short-term memory. *Cognition*, *208*, 104534–104534.

Peretz, I., & Morais, J. (1987). Analytic processing in the classification of melodies as same or different. *Neuropsychologia*, *25*(4), 645–652.

Pruitt, T. A., Halpern, A. R., & Pfordresher, P. Q. (2019). Covert singing in anticipatory auditory imagery. *Psychophysiology*, *56*(3), e13297-n/a.

Saarikivi, K. A., Huotilainen, M., Tervaniemi, M., & Putkinen, V. (2019). Selectively enhanced development of working memory in musically trained children and adolescents. *Frontiers in Integrative Neuroscience*, *13*, 62–62.

Sabri, M., Kareken, D. A., Dzemidzic, M., Lowe, M. J., & Melara, R. D. (2004). Neural correlates of auditory sensory memory and automatic change detection. *NeuroImage*, *21*(1), 69–74.

Schubert, E., & Stevens, C. (2006). The effect of implied harmony, contour and musical expertise on judgments of similarity of familiar melodies. *Journal of New Music Research*, *35*(2), 161–174.

Schweppe, J., Schütte, F., Machleb, F., & Hellfritsch, M. (2022). Syntax, morphosyntax, and serial recall: How language supports short-term memory. *Memory and Cognition*, *50*(1), 174–191.

Tan, S.-L., Pfordresher, P., & Harré, R. (2010). *Psychology of music: From sound to significance*. Psychology Press.

Temperley, D. (2023). Melodic pattern repetition and efficient encoding: A corpus study. *Empirical Musicology Review*, *18*(2).

Tervaniemi, M., Rytkönen, M., Schröger, E., Ilmoniemi, R. J., & Näätänen, R. (2001). Superior formation of cortical memory traces for melodic patterns in musicians. *Learning and Memory*, *8*(5), 295–300.

Trainor, L. J., McDonald, K. L., & Alain, C. (2002). Automatic and controlled processing of melodic contour and interval information measured by electrical brain activity. *Journal of Cognitive Neuroscience*, *14*(3), 430–442.

Zhang, J. D., Susino, M., McPherson, G. E., & Schubert, E. (2020). The definition of a musician in music psychology: A literature review and the six-year rule. *Psychology of Music*, *48*(3), 389–409.

Zuk, J., Benjamin, C., Kenyon, A., Gaab, N., & Bruce, A. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLOS One*, *9*(6), e99868–e99868.