

# Is Pitch Information Indispensable for Music Recognition? A Pilot Study Based on a Musical Matching-Pairs Game

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Musical memory is essential for music cognition research. By investigating musical memory, researchers can examine and better understand how musical patterns are represented in memory. Although previous empirical studies have established the importance of pitch and rhythm in music recognition (Dowling, 1978; Dowling & Fujitani, 1970), recent research suggests that other less obvious representations like timbre may have been overlooked (McDermott et al., 2008). Further, only a few studies on musical recognition have been conducted where listeners are presented with music that they would attend to in everyday listening. To investigate the cognition of familiar music, we introduce and examine a set of three tools that can be used to probe musical memory in more naturalistic settings. These include 1) a novel corpus of television introduction tracks (*TeleTunes*), 2) the use of a noise vocoder to manipulate pitch in realistic music, and 3) a musical matching-pairs game testing musical memory. In this paper we demonstrate how this set of tools can be used to investigate questions of music perception and cognition in more ecological settings and lay groundwork for using the *musical matching-pairs* game in our future research on music and memory.

**Keywords:** pitch degradation, noise vocoding, musical matching-pairs game, memory, musicality

## 1. Introduction

An important research question in the study of music cognition is: what makes music memorable. The cognitive processing of music can be understood as a process consisting of several steps: a listener needs to encode what they hear by extracting a generalized, invariant representation of the music they have heard, and then store it for later retrieval (Snyder, 2000). Just as after listening to a story, we remember salient features like the name of the main character or what happened, as opposed to remembering the story word-by-word, some aspects of a musical ‘story’ may be salient to musical listeners. By investigating what makes music memorable, music cognition researchers can examine the role of the core components of music perception and understand how auditory patterns are represented in our memory.

### 1.1 Is Pitch Information Indispensable?

One of the most studied aspects concerning musical memory is pitch. To better understand the mechanisms of perceiving pitch – more specifically *relative pitch* – Dowling and Fujitani (1970) examined the performance on a musical recognition task by representing pitch using contour and interval as two common components of relative pitch (Dowling, 1978; Dowling & Fujitani, 1970). *Contour* is defined as the directional relationships between the sequence of notes (i.e., interval size does not matter), whereas intervals represent the exact pitch distance from note to note (i.e., *interval*). They concluded that both contour and interval are critical to recognition for familiar melodies, whereas recognition is dominated by the contour for novel melodies. Based on Dowling’s paradigm, McDermott et al. (2008) continued to examine whether contour as a relative representation, is unique for relative pitch, or other

dimensions of music also would generate relative representations. They incorporated two additional representations: *brightness* and *loudness* contours. This was done to probe whether relative representations for other dimensions of sound could be used for music recognition. Their results demonstrated that participants can extract contours of brightness and loudness – similar to how they extract contours of relative pitch – as relative representations to recognize familiar melodies. This result suggests that contour representation may be a general feature of the auditory system that is also present in other aspects of music.

### 1.2 Ecologically Valid Experimental Paradigm

Research like that of McDermott, Dowling and Fujitani exposes participants to sound sequences that are not the music they would listen to in their everyday lives. The two studies involved tasks of determining whether two randomly generated five-note melodies are identical while systematically manipulating other aspects of the melodies that participants heard. Designs like this predominantly focus on creating well-controlled stimuli to isolate specific variables to accurately assess their effects. While these are important insights, the generalizability of these findings to real-world contexts can be limited.

Furthermore, the paradigms used in the studies discussed above were conducted in well-controlled laboratory settings. Such settings often do not resemble how most people listen to music. Using an experience sampling methodology, Sloboda et al. (2001) listed the locations where participants heard music, including home, transport, work, and the gym, with only a small fraction of experiences being categorized as ‘other’. This ‘other’ category is the

type of situation where a listener might find themselves in a psychology study. If we, as music researchers, want empirical data to be representative of how people listen to music, it is important to come up with paradigms that capture listeners in environments that are familiar to them to have our findings be representative of everyday listening.

### 1.3 Games Are An Alternative

One solution that meets both requirements of having people listen to music they find familiar in familiar environments is to develop musical games that people can play (Honing, 2021). One example of this is *Memory*, the popular and accessible card game played by children and adults around the world (Zwick & Paterson, 1993).

To play the game, players are presented with a board of multiple cards that contains  $n$  pairs. Taking turns, players flip two cards at a time. If the two flipped cards are identical, they are deemed a pair and the pair is removed from the board. The game ends when the board is cleared, and the player who matched most pairs is the winner. While *Memory* is typically played with multiple players, the game can also be played in solitaire. In a solitaire version, the goal of the game would be to try to clear the board with as few turns as possible. We might also assume that players who can clear the board in less turns will have a higher ability to play the game than those who take more turns.

Inspired by the card game *Memory*, we developed an online version of the game where instead of matching images, players make matches by listening to music fragments. Creating a game that people can play anywhere allows us to collect data from listeners wherever they are, which we believe provides a more ecological context that represents everyday listening. The novelty of the musical matching-pairs game also lies in its fun nature, contrasting with traditional laboratory-based data collection. A fun-to-play music game encourages participants to enjoy the natural process of playing and can reduce fraud and drop-out (Burgoyne et al., 2013). Due to the game mechanics, participants are providing objective responses, as only if they choose a “matching” pairs of music fragment can they proceed further and eventually complete the game. This means that their performance in the game depends on and reflects their recognition and memory abilities.

Additionally, to ensure that people hear music that resembles music they would hear in everyday listening, we are in the process of developing a novel corpus of themes from famous television and movies from the past 40 years. By doing so, we also ensure that what participants hear in our game is already stored in their long-term memory, meaning in turn that their performance might be less confounded by potential factors such as learning pace or individual memory ability, i.e., the recognizability of the music to be free from the noise of how quickly a new melody is memorized or how it is learned during the game.

We believe that the use of familiar music increases the ecological validity of our experiment, in the hope resulting representative data of how people respond to and process musical information in natural settings.

While using familiar music has several ecological benefits, the music on its own does not allow researchers to examine specific attributes of the music. Unlike Dowling and McDermott, who created sound sequences with only the properties they wanted to examine, we systematically manipulate existing familiar music. For this we take advantage of state-of-the-art signal processing techniques to systematically degrade aspects of music we wish to investigate. These types of methods have been relatively successful in many fields related to music perception and cognition. For example, Bregman et al. (2016) showed that songbirds use *spectral shape* instead of pitch for sound pattern recognition by presenting songbirds with sound recordings that have been noise vocoded to degrade pitch. Using these techniques, they demonstrated that even in the absence of pitch, as long as the spectral shapes of the constituent tones are preserved, songbirds are able to recognize the melody. We plan to use a similar logic by using musical stimuli that have been noise vocoded (Davis et al., 2015) to degrade perceptually valid pitch information, but in the context of humans playing a memory game. By degrading pitch information, we will be able to investigate the importance of pitch in music memory.

### 1.4 Study Aims

As a proof of concept of using the matching-pairs game as an alternative to a lab-experiment, we introduce and investigate three crucial components of our proposed design, in the hope to illustrating the rationale of adopting this paradigm for studying musical memory. We present first how the TV themes were collected to form a corpus; Secondly, how the pitch information was manipulated using a signal processing approach: noise vocoding (Davis et al., 2015); Finally, how we determine a range of optimal board sizes that might maximize the discrimination ability of the game.

## 2. Methods

### 2.1 Corpus: TeleTunes

To ensure the ecological validity as well as familiarity of the stimuli, we developed a novel corpus for our study. *TeleTunes* is a corpus that consists of theme music from popular TV shows. TV shows commonly encompass numerous episodes and can span across multiple seasons; they also often engage viewers over an extended period of time. Additionally, the opening music is typically played at the beginning of each episode, and the theme music is typically played at the iconic and meaningful moment throughout the show. Such repetitive listening behavior, occurring in a natural music listening setting, contributes significantly to the desirable

characteristics of being ecologically valid and familiar.

We first created a list of tracks by combining the Top 100 most-watched TV shows from the Internet Movie Database (IMDB, Top 100 Most Watched Tv Shows of All Time - IMDb, n.d.) with two lists of the top 100 "Greatest" TV shows from Rolling Stone (published in 2022 and 2016; Alan Sepinwall, 2022; Rob Sheffield, 2016). This process produced a collection of 224 tunes from popular television programs spanning the years 1972 to 2018. As our brains are particularly sensitive to the human voice (Weiss et al., 2017), we removed 147 stimuli from the corpus that contains either lyrics or monologues to avoid possible confound. From the remaining 77, we found 48 tracks that can be purchased from online digital media service for copyright reasons (iTunes store and Qobuz). Then, through careful listening, we selected meaningful or structural starting points within each piece of music and trimmed 30-second fragments with those points as the start point. Additionally, we subjected all the fragments through the Hooked-on Music (Burgoyne et al., 2013) – an experiment that was able to identify the catchiness of the music. This experiment comprises a recognition task, a verification task, and a prediction task as a mechanism to be able to determine whether the subject actually remembers a song. Hence, it serves as a pre-selection procedure to make sure the final corpus consists indeed with very familiar music. Finally, we further trimmed each fragment to 10 seconds long to suit the gameplay purpose.

## 2.2 Manipulation (Degrading Pitch)

We used the software *Praat* (Boersma & Weenink, 2023) to create two noise vocoded versions of each original track, more specifically, we applied a noise vocoding algorithm (Winn et al., 2012) to remove perceivable pitch from our original tracks. The two versions of the tracks were intended to represent two levels of degradation, meaning that some pitch information is still recognizable in the first level degradation, while it is not perceivable in the other (second level degradation). To achieve this, we batch processed our corpus using the following parameters: lowCornerFreq: 100, highCornerFreq: 8000, numberStimulated: 50 (first level) and 25 (second level)/ rolloff.per.mm: 50, envelope cutoff filter (Hz): 100 and option of “use Hilbert” selected, while all the other parameters were set to their defaults. Number of stimulated and channels are the key parameter resulting in two different pitch perception level. Such difference was confirmed in a pilot study ( $N=10$ ).

## 2.3 Simulation

Developing a paradigm that functions both as a science experiment and as a musical game poses a challenge: to strike a balance between being enjoyable and providing psychometrically valid data. From an engagement perspective, the game needs to be not so difficult as to frustrate the player, whereas from a

psychometric perspective, the experiment needs to achieve discrimination through sufficient difficulty. We need to ensure that players are not able to complete the game by luck. In other words, the data generated by the game should effectively reflect the player’s recognition ability.

When conceptualizing a musical matching-pairs game for research data collection, we recognize the board size (i.e., number of pairs) involved in game play is the crucial aspect in achieving the above claims. The difficulty of a memory game increases as the size of the game board grows larger. This is because with a larger board, there are more cards to remember and match. As a result, players need to retain and recall a greater amount of information (i.e., the specific locations and identities of the cards) to successfully find the matching pairs.

To estimate the optimal board size to navigate between a game being too easy and too difficult, while still retaining useful psychometric properties, we ran two simulations of various board sizes. The first set of simulations modeled what game play performance on the musical matching-pairs game would look like if a player played the game only using random click and no memory for what they had heard before (hereafter referred to as *chance*). The second set of simulations modeled game play performance of a player with perfect memory (hereafter referred to as *perfect*). Game performance was represented by the number of turns it takes to clear the board. We anticipate that the performance of actual participants will fall between these two extremes.

We operationalized perfect condition in our paradigm with adopting a strategy where the player would explore every card at least once to learn the position and content of all cards. Because the player never forgets the location and contents of each card, in the second round, every pair they turn over will be a match. As finding what we refer to as a *lucky match* might happen during the first exploration round, there are cases where the number of turns to complete the game will be less than the number of pairs in the second round. For example, in a board size of 8, which has 4 unique pairs of {A1, A2, B1, B2, C1, C2, D1, D2}, the maximum number of turns needed to clear this board would be equal to the number of pairs assuming there were no lucky matches during the initial search. The maximum length search might consist of flipping {A1, B1}, {A2, B2}, {C1, D2}, and {C2, D1}, which takes four turns to learn the location of all pairs with no lucky matches, then another four turns in the second round to perform the correct matches of {A1, A2}, {B1, B2}, {C1, C2}, and {D1, D2}.

By contrast, in the chance condition we simulate a situation where the player does not remember the location and contents of each card. The process of playing the game is completely random. On each turn, the player would explore two cards, if the two cards are a lucky match, they will be removed from the

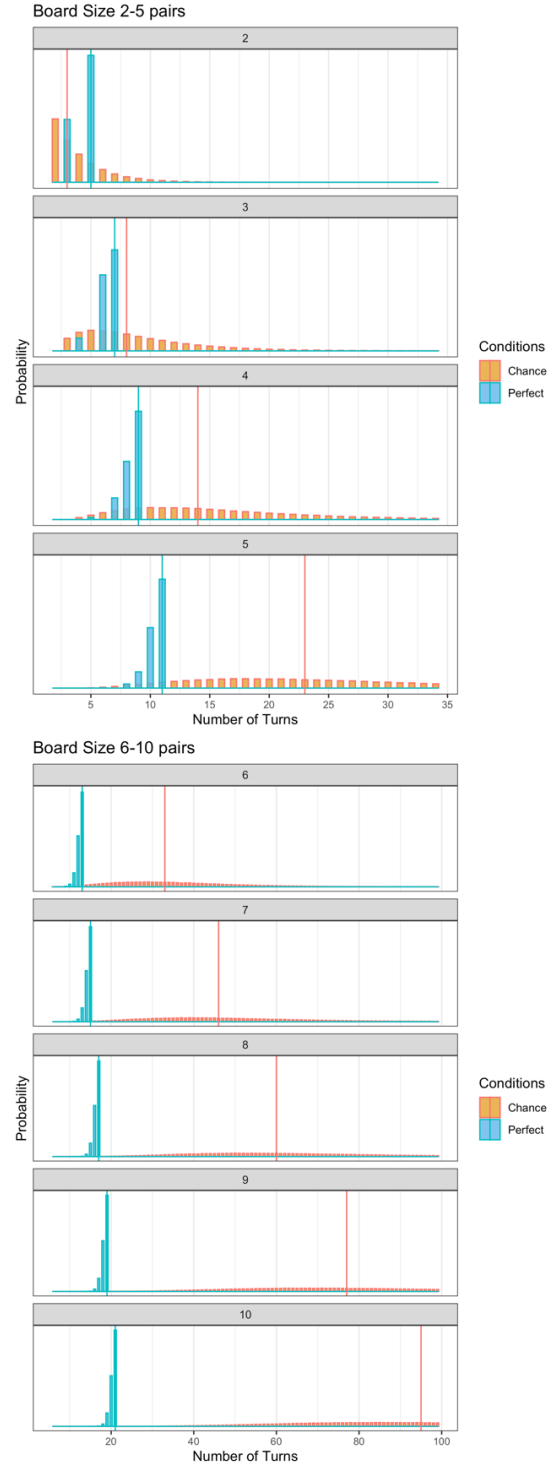
board; otherwise, they will be flipped back and the board remains unchanged, and the player will continue to explore next two cards in next turn. The game is finished until all the cards on the board are removed by lucky matches. Here again we take the case where the board size is 8, containing  $\{A1, A2, B1, B2, C1, C2, D1, D2\}$  as four unique pairs. In the first turn, the player explored D1 and B2 for example (could be any other two cards), they do not match, then D1 and B2 will be flipped back, and the board will remain a full board. On the second turn, the play can still inspect these two cards (as no memory on which cards has been inspected) or other cards. Until the first lucky match occurs, the remaining cards on the board will be reduced by 2. Players will then repeat this process until the board is cleared.

Our goal in running this set of simulations was to estimate the median number of turns given both conditions (perfect and chance) and board sizes of 2 through 10. Size of board refers to the number of pairs, so a board of size 2 will have four cards. The simulations here were ran based on 100,000 iterations and run using the R programming language (R Core Team, 2017). The results of our simulation are shown in Figure 1.

Concerning our simulation analysis, we computed the median number of turns needed to solve a board given various sizes and conditions. The median number of turns for a chance and perfect player to solve the game is represented by the two vertical lines in Figure 1 (colored orange and blue respectively). Under the assumption of a normal distribution, the median is expected to signify the area where the majority of human data points are concentrated. It is plausible to assume that the median of human performance is likely situated between the medians of these two extreme conditions.

As shown in the top panel of Figure 1, when the board consists of only 2 unique pairs (i.e., 4 cards), it would be nearly impossible to differentiate between chance and perfect memory performance without having massive amounts of data, as the two distributions share a considerable amount of overlap. As expected, as we increased the number of pairs on the board, the distance between the distributions begins to diverge. When the board size reaches a specific number, the gap between the medians of the turns needed to finish the game under these two extreme conditions will be large to encompass the varying performance levels of the participants.

As an even number of pairs provides a more visually attractive layout, allowing for the formation of symmetrical rectangles or square boards with cards of uniform size, based on our simulation analysis, we've identified board sizes of 6, 8, or 10 pairs as potential starting points. For current stage we decided a board size of 8 pairs for the pilot study. A 4 by 4 board could prevent card distortions caused by screen aspect ratio variations, fitting comfortably on either a mobile device (vertical) or a computer screen



(horizontal). Furthermore, this approach enabled us to verify the difficulty of the game during the pilot study.

**Figure 1.** Simulation of Chance and Perfect Strategy Given Board Sizes of Two through Ten Pairs

*Note.* The Vertical lines shows the median number of turns for a chance and perfect memory player to solve a board of size X pairs ( $X = 2 - 10$ ). The number displayed at the top of each panel signifies the board size.

If the game proves too challenging for most players, we can adjust to a smaller board size of 6 pairs. Otherwise, we can opt for a larger board size of 10 pairs. By doing so, we hope to capture the full range of human behaviors that might result from game play.

#### 2.4 Game-design

In the pilot version of the matching-pairs game, participants were presented with a 4 by 4 board of cards that responded to either the click or touch of the user. The 16 cards corresponded to 8 pairs music fragments of familiar TV tunes. The selected fragments and location on the board were randomized for each game. Each pair of the stimuli consisted of one original fragment and its degraded version. A *match* means that the original TV tune clip and its corresponding pitch degraded version are selected in one turn. Alternatively, it was a not a match. N.B. A match comes in different versions (see below).

Participants were instructed to flip two cards one after another in each turn to listen to the music fragments. Feedback of their score was provided after each turn at the top of the board. Based on the participants' responses for each turn, feedback was given in the following categories: 1) no match and not seen before, 2) match by chance, 3) match and seen before, 4) no match but seen before. These are displayed to participants as *no match* (0), *lucky match* (+1), *good job* (+2) and *misremembered* (-1) (with the amount of score points indicated between brackets.) We set the starting score at 100 to not discourage participants as there is a high probability of multiple incorrect pairings (i.e., no match) at the beginning of the game. We recorded the reaction times, number of flips for each card, card location and whether the responses were correct for each participant and each turn.

#### 2.5 Procedure

The game consisted of four main sections that the participant will interact with: 1. Informed Consent and instructions, 2. Gameplay (with Feedback) 3. Demographics, 4. Final Feedback / Play Again.

Upon accessing the game, participants were first asked to provide consent for the study, then participants are allowed to play the game as many times as they chose. After each turn in the game, a score change that aligned with the scoring is displayed on the screen. Upon completion of the game, participants are asked about their demographic information. These questions included birth year (choosing from 15-year intervals), gender, music experience level (no / moderate / extensive / professional), education level, and country of residence during formative years. The final question intended to probe how familiar they are with the music played in the game and then given a final score. This information is stored so that a participant could simply continue playing the game if they return to the game page.

### 3. Discussion

This paper presents a comprehensive examination of three fundamental components essential to using the musical matching-pairs game in music cognition research. These three components include a novel TV tunes corpus, *TeleTunes*, the pitch manipulation using noise vocoding technique, and the key factors concerning effective implementation of the game. We have also presented an outline of the game design and procedure.

We formed a novel *TeleTunes* corpus with a careful procedure to ensure familiarity and ecological validity in our original experimental stimuli. We then applied the noise vocoding technique to manipulate the stimuli, resulting in the creation of two distinct levels of the pitch-degraded corpus.

The utilization of the TV corpus in conjunction with the noise vocoding technique has several implications for music cognition. By employing a familiar and ecologically valid corpus of TV show stimuli, we can effectively capture real-world auditory experiences and enhance the ecological validity of the experiment.

The manipulation of the stimuli through noise vocoding provides an opportunity to examine the recognizability of music when pitch-information is less or not detectable. This would allow us to answer our question of whether pitch is dispensable in music memory. With the availability of multiple levels of the degraded corpus, we could explore a dose-response relationship between the degree of degradation and its effects on participants' responses. Furthermore, it could potentially provide us with useful information on whether there are relative representations of other aspects of music (e.g., its temporal and spectral structure) that are sufficient to recognize music when pitch information is not available anymore. This would allow us to model the degree to which aspects of music like rhythm or timbre affect memory.

The simulation of perfect and chance performance as two extreme conditions has demonstrated the range of possible human gameplay outcomes. We were thus able to further determine the optimal board size – allowing us to capture the variation of human performance while keeping the game enjoyable.

#### 3.1 Limitations

Our current study is not without several important limitations that need to be addressed in the future. First, the simulation study only approximates the differences between chance and perfect performance, assuming that human performance will fall between these two extremes. However, this analysis overlooks some key factors in establishing this game a valid psychometric instrument. One such factor is the difficulty level of the game's tasks. Another is the abilities of the player. In the next step of the study, we will adopt more sophisticated models to assess these two factors. For example, the Rasch Model based on item response theory (De Ayala, 2018).

Concerning the TV Tunes corpus, while trying to include works from different countries and regions in the current *TeleTunes* database, at the moment, it still exhibits a cultural bias by predominantly featuring music from Western mainstream TV shows and digital media store. As a result, the generalizability of findings derived from the *TeleTunes* corpus may be limited, especially when considering broader populations beyond Western cultural contexts. To further improve the cultural adaptability of the TV corpus, it is important to work towards a future that incorporates soundtracks of popular films and TV shows from different cultures.

### 3.2 Applications

Despite these (current) limitations, we believe that the matching-pairs paradigm can be valuable for music perception researchers for several reasons. The first is that the game is fairly easy to learn, meaning that minimal instructions need to be given to learn to play the game. This makes the game well suited for working across cultures, as well as across the developmental lifespan. Further, though we have focused on the use of noise vocoding to eliminate pitch information from familiar music, several other techniques could be used to make different meaningful manipulations. Inspired by Albouy and colleagues (Albouy et al., 2020), the use of the spectro-temporal modulation algorithm (STM) might be used to degrade information in either the temporal or timbral dimension. It would be beneficial to apply various manipulations to the same corpus. We could then monitor how subjects perform in recognition and pairing tasks under various condition. This approach would enhance our grasp of how different music aspects contribute to music memory.

### 3.3 Conclusion

In this paper we have put forth a new paradigm of the musical matching-pairs game. This game is proposed as an innovative tool for probing musical memory within the research field of music cognition and perception.

Our discussion encompassed the game's capacity to address two pivotal facets of ecological validity: the stimuli employed and the experimental design. We presented the advantage of a unique corpus *Teletunes*, composed of TV introductions and themes. We also simulated the effects of various board sizes. These simulations allowed us to draw connections between these board size variations and their implications on general gameplay. Additionally, we incorporated a signal processing technique known as noise vocoding. This integration allows for the systematic degradation of pitch information from experimental stimuli, in the hope of providing unique insights into how music is perceived and processed.

In summary, we demonstrate its potential for studying memory in music cognition and perception studies. We believe this lays a foundational

groundwork for using the musical matching-pairs game in future research of the field.

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