Online Games for Perceptual Learning: Assessing Acquired Affective Connotations of Sounds

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Abstract

Understanding how perceptual judgements develop requires methods that capture both existing biases and their susceptibility to short-term experience. We present an online game-based paradigm designed to investigate how affective responses to sounds can be shaped by exposure. 48 participants first completed an affective priming task to establish baseline associations. They then played a simple game in which specific sounds were systematically paired with positive or negative in-game events, providing a controlled but engaging learning environment. A second priming task assessed post-exposure changes. Initial findings indicate that explicit self-reports show consistent shifts in valence judgements aligned with the in-game contingencies, whereas the results on priming are weaker and reach significance only partially. Improvements to the design and implementation are discussed. Overall, the results suggest that the paradigm can capture the experience-dependent modulation of affective perception of sounds while also highlighting the distinction between explicit and implicit measures. The approach offers a general framework for studying short-term plasticity in perceptual cognition.

Keywords: perceptual learning; valence perception; music cognition; implicit measure; online experiment; game-based methods; priming paradigm

Introduction

Much of the past research on music cognition has captured Western processing of music, which has demonstrated that learning acquired in one's culture shapes the fundamentals of music perception and cognition in many ways (Jacoby et al., 2024; Klarlund et al., 2023). Although cross-cultural research is perhaps the most potent way to demonstrate differences (Jacoby et al., 2020), it is also possible to trace how perception is shaped through developmental studies (Virtala, Huotilainen, Partanen, & Tervaniemi, 2014; Trehub, 2003). However, a direct way of exploring the acquisition of music perception elements is to use a *learning paradigm* (Sarasso et al., 2021; Perruchet & Pacton, 2006).

The study of music perception has occasionally taken advantage of learning paradigms to elucidate the cognitive processes involved. Research has highlighted the interconnections between music training and the enhancement of auditory perception skills, whether these are related to rhythms (Ning, Trosman, Sabin, & Wright, 2018), sequence learning (Laubrock & Kinder, 2014), or melodic expectations (Pearce & Wiggins, 2012; Rohrmeier, Rebuschat, & Cross, 2011), musical grammar (Loui, Wessel, & Kam, 2010; Rohrmeier et al., 2011), dissonance (Omigie, Dellacherie, & Samson, 2017), suggesting that long-term exposure to music cultivates perceptual advantages that can be empirically evidenced.

The evidence for supporting the acquisition of new statistical regularities conveyed through a learning paradigm can be achieved through explicit or implicit tasks. Explicit tasks are those where participants are directly asked to rate or classify choices related to the property they have learnt. The downside is that such tasks are subject to demand characteristics that tend to bias explicit measures (Coles, Wyatt, & Frank, 2025). To counteract these shortcomings, several implicit measures have been developed, such as incidental learning and discrimination task (Leung & Dean, 2018), or the priming paradigm (Hermans, Vansteenwegen, Crombez, Baeyens, & Eelen, 2002). These measures eliminate demand characteristics and social desirability biases, although there are also doubts about the underlying claims (Ramscar, 2016).

The affective priming task has been used to explore various qualities of music, such as whether chords are positive or negative (Lahdelma & Eerola, 2024a; Sollberger, Rebe, & Eckstein, 2003). In an affective priming task, participants are presented with two stimuli in succession, one called *the prime* and *the target*. When exploring affective priming of musical sounds, the primes consist of sounds, and the targets are typically (negative or positive) words. It is accepted that targets are classified more rapidly when the prime and target are congruent in valence (both positive or both negative) compared with incongruent pairings. Interestingly, there has been an attempt to separate specialist knowledge embedded in music culture by explicit (self-report) and implicit measures (priming) of dissonant intervals among Lithuanian Sutartinė singers and non-specialists from Lithuania and the UK (Armitage, Lahdelma, Eerola, & Ambrazevičius, 2023). The results of this recent suggested that while learning demonstrates clear self-reported differences between experts and non-experts of the musical culture, implicit measures failed to support the notion that the knowledge provides automatic and implicit advantage in processing the intervals.

Several distinct mechanisms may contribute to the learning processes engaged during gameplay, including perceptual learning, associative learning, and classical conditioning. In the present work, we use the term perceptual learning in a broad, umbrella sense to encompass these possibilities, ranging from changes in perceptual representations in a

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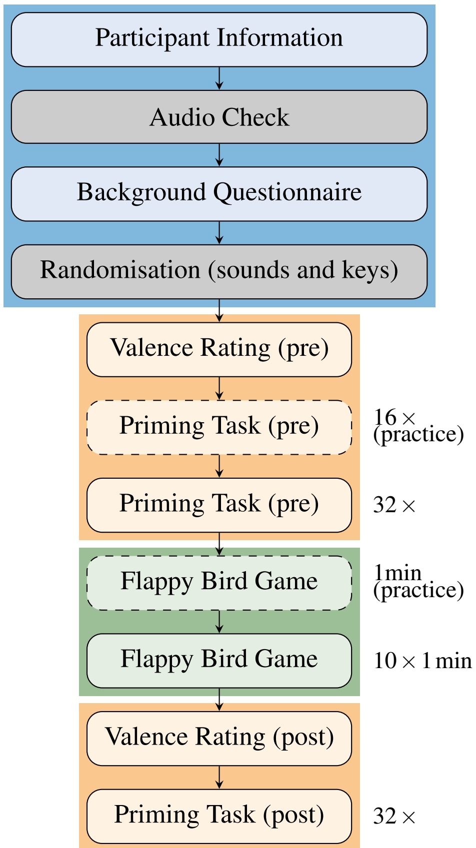

Figure 1: Experimental procedure with four stages: Setup, Pre-Assessment, Learning Game, Post-Assessment.

narrow sense to shifts driven by associative or conditioning processes. Importantly, we do not assume that these mechanisms are theoretically identical or operate at the same level of cognitive representation. Rather, the present study is agnostic with respect to the precise underlying mechanism driving any observed changes in affective responses. The primary objective is methodological: to introduce an experimental paradigm that enables the controlled induction and measurement of changes in stimulus–response associations through short-term experience. In this context, the online game serves as a tool to systematically manipulate experience and assess whether such changes occur at all, independent of whether they arise from conditioning, associative processes, or other forms of learning. Disentangling these mechanisms constitutes an important direction for future work but lies beyond the scope of the current study.

Methods

Experimental Procedure

The general experimental procedure is shown in Figure 1 and consists of four stages.

Setup The setup stage contains the usual procedures to ensure that the experiment runs smoothly. In particular, we provide participants with an introduction to the experiment and collect their informed consent, do some simple audio checks (typing words they hear) to ensure audio is working and at a comfortable level, collect some participant background information, and initialise all participant-specific randomisation.

For the background questionnaire, we collected participants' gender (*male; female; other; prefer not to say*), age, and musical self-classification (*Which title best describes you? Nonmusician; Music-loving nonmusician; Amateur musician; Serious amateur musician; Semiprofessional musician; Professional musician*) as a proxy of musical sophistication (Zhang & Schubert, 2019).

Assessment We assessed valence before (pre) and after (post) the game using two different methods.

The first was an explicit *valence rating* of the sounds (viola and tubular bell) on a continuous scale from most negative to most positive, using a horizontal slider initialised at the centre of the scale (*How would you rate the following sound ranging from most negative to most positive?*). Explicit ratings tend to give consistent results with little noise, but may be affected by demand characteristics when participants (consciously or unconsciously) adjust their responses to align with perceived experimental expectations.

The second assessment method was a *priming task*, in which participants were presented with a series of target words, which were to be categorised as positive or negative and the reaction times of the decisions were collected. There were 32 trials in which each sound (viola and tubular bell) was paired with all positive (8) and negative (8) words, each word taken from (Warriner & Brysbaert, 2013) (also see the Materials section). In the paradigm, the fixation cross initialises each trial, and the sound is presented 200 ms prior to the appearance of the word. The participant's decision about the word valence is made with the keyboard. The keyboard shortcuts ('F' or 'J') are randomly assigned to each participant separately. The participants first did 16 practice trials of the priming task (each word once) without the sounds to learn the task and the keys to use before doing the actual priming task with sounds.

Learning Game The learning game consists of 10 rounds (1 min each) of a Flappy Bird clone (Figure 2), created with JavaScript and PixiJs[1]. The two sounds are explicitly associated with negative events (hitting a gate) and positive events (passing a gate), respectively. The valence is clear from the context of the game and also emphasised visually: when passing a gate, a green "+100" shows next to the bird and the total score at the bottom is incremented by 100 points; when hitting a gate, red highlights appear around the bird, the screen very briefly flashes red, and the score is decremented by 100 points.

The difficulty was automatically adjusted (by increasing/decreasing the gates' height and distance) to achieve

[1] https://pixijs.com/

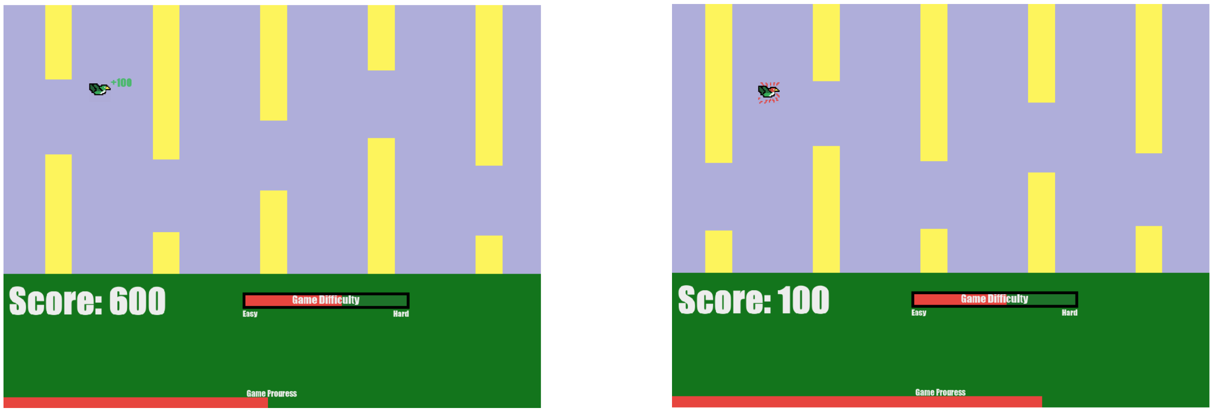

Figure 2: Flappy Bird Clone: Left: successful pass of a gate, right: clash with a gate. Each trial lasts 1 minute and the difficulty automatically adapts to achieve an approximately equal number of successful passes and clashes (and thus approximately equal exposure to both sounds).

an approximately equal exposure to both sounds. We randomised the sound-valence pairing for each participant to counter any inherent biases that the sounds themselves might have.

Materials

Sounds Two relatively neutral instrument sounds, tubular bell and viola, were selected to provide a plausible starting point. The sounds were derived from the Vienna Symphonic Library, originally used in timbre and emotion research (Eerola, Ferrer, & Alluri, 2012) and normalised by setting them to the same peak sone level.

The selection of stimuli was guided by the aim to minimise a priori valence differences while ensuring perceptual discriminability. Two acoustically distinct sounds (tubular bell and viola) were deliberately chosen to avoid direct comparison along a single timbral continuum, which could induce systematic valence biases (e.g., harsher timbres of the same instrument being perceived as more negative). Using highly similar sounds would increase the likelihood of such relative judgements and confound the interpretation of learning effects. At the same time, clear perceptual distinctiveness facilitates the formation of new stimulus–outcome associations during the learning phase. To further control for baseline differences, implicit and explicit valence associations were measured prior to the game, confirming the absence of strong initial valence biases. This design prioritises both neutrality and discriminability of stimuli as prerequisites for assessing experience-dependent changes, but future studies may choose more similar sounds.

Words The words used in the priming task were taken from (Warriner & Brysbaert, 2013) and consisted of eight positive (“sweet”, “lively”, “gentle”, “cuddle”, “excite”, “kiss”, “comfy” and “relax”) and eight negative words (“rabid”, “hijack”, “death”, “vomit”, “arrest”, “fatal”, “dismal”, “morgue”). The selected words are similar in lexical frequency and length, but exhibit significant valence differences, but no arousal differences. The same collection of words was used successfully in a recent chord priming study (Lahdelma & Eerola, 2024b).

Participants

50 participants were recruited from Prolific.com, a crowdsourcing platform designed especially for research purposes. Before analysis, 2 participants were removed from the dataset due to more than 20% timeouts in the priming task. The sample (N=48) had a mean age of 24.08 (SD = 3.67), and 60.4% of the participants were women and 87.5% were nonmusicians. Participants received £12/h for participating in the study, and the study received ethical approval.[2]

In the priming task, incorrect responses to individual items were removed from the data set (86 in total, 2.8%), as were timeouts (>1500 ms, 222 in total, 7.2%) and too fast responses (<200 ms, 1 response).

Results and Discussion

The self-reports and reaction time data were fitted to a mixed generalized model (Lo & Andrews, 2015), using the `lme4` R library (Bates, Mächler, Bolker, & Walker, 2015) with the fixed effects of the Session and Valence condition and the Participant as a random effect. Reaction times were logarithmically transformed for statistical analysis, but not for the visualisation.

Explicit task

In explicit valence ratings, there were no significant main effects concerning Sound, Session, or Associated Timbre (all t $<$1.1, p $>$.25), which confirmed the assumptions (the sounds are equally pleasant and there are no inherent differences related to associated timbre or the session). However, our main objective of the analysis was to test the interaction between

[2] Approval ID omitted to preserve anonymity.

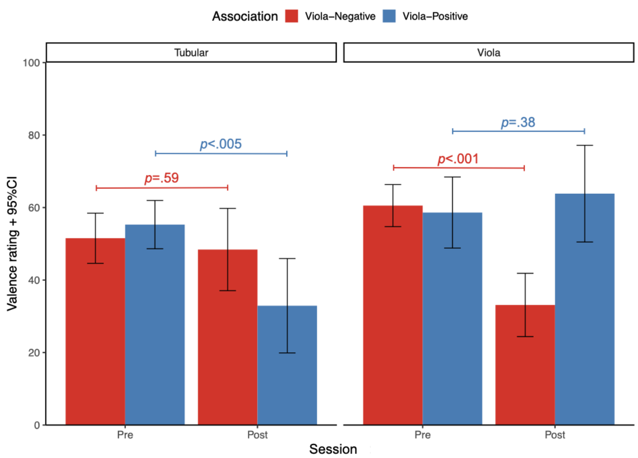

Figure 3: Explicit valence ratings (from 0-100, where 0 is maximal negative valence and 100 maximal positive valence).

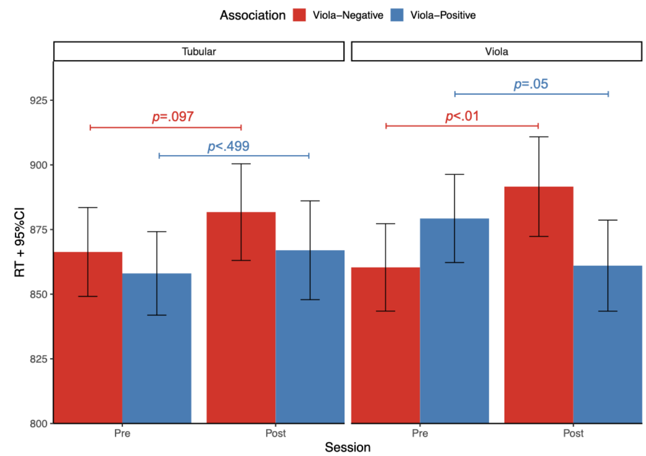

Figure 4: Implicit priming task (reaction times in ms).

Sound, Associated timbre, and Session, which was significant (t[138] = 4.47, p <.001). In other words, depending on the timbre association the participants were assigned to, the negatively associated sounds were consistently rated more negative after the learning game (see Figure 3). Subsequent tests with planned contrasts further clarify that both sounds could be altered to reflect *decreases* in valence ratings after the learning game (see contrast results by condition in Figure 3), but statistically significant *increases* in valence ratings were not observed. The results suggest that the learning paradigm can render both sounds as more negatively valenced, but the opposite trend remained unobserved, which may be related to an inherent risk aversion where the negative events are more salient and experienced more intensely than the positive events (see Rozin & Royzman, 2001). However, the main finding about the learning game being able to modify the valence of the sounds can also be explained with demand characteristics, as the pairing of the two sounds with positive and negative events, respectively, is quite obvious.

Implicit task

The implicit assessment of learning was carried out through the priming task, where the reaction time to decide whether a word is positive or negative whilst primed with the associated sounds is considered to provide an implicit measure of valence and thus learning (see Figure 4). There was a weak, albeit statistically non-significant interaction between Sound, Associated timbre, and Session (t[2603] = -1.87, p= 0.062), suggesting that the implicit task did not mirror the findings of the explicit task. However, there is a significant interaction between Sound and Associated Timbre (t[2603] = 2.11, p <.05), suggesting that the associations imparted through the learning game are stronger for the viola than for tubular bell sound. Further contrast analyses suggest that the negative association imparted in the learning game to the tubular bell has little impact on the implicit measure (p=.49), while when used to convey a positive association, the reaction time produces results trending towards significance (p=.098). In contrast, the viola sound does provide significant effects when used to train negative (p<.01) and positive associations (p<.05).

The results suggest that the implicit measure is sensitive to learned associations acquired through the simple learning game, but that the strength of these associations is influenced by timbre and is probably also qualified by the number of observations available for the analysis. For the viola sound, the explicit task already indicated that this timbre is more conducive to forming positive associations. The tubular bell, by contrast, does not lend itself to such timbral malleability, which in itself is an interesting finding. Previous studies on emotion perception in instrument sounds suggest that viola timbre, potentially due to its slower attack rate and lower spectral brightness, tends to be associated with more positive valence than percussive instruments such as the tubular bell, which typically have a fast attack, high spectral energy, and inharmonic partial structures that are generally linked to less positively valenced sounds (Eerola et al., 2012; Korsmit, Montrey, Wong-Min, & McAdams, 2024). It may be that percussive sounds are less malleable in general regarding emotional associations, as the characteristic envelope and inharmonic components make them more distinct and less pleasant compared to non-percussive sounds such as strings, woodwinds, and the voice (see e.g., Huron, Anderson, & Shanahan, 2014).

Improvements

Although full symmetry in achieving learning effects on implicit measures with both sounds was not supported, the results still suggest that the learning game had an influence on the perceived valence of the sounds. The first clear way to move forward is to conduct a larger follow-up study. In particular, one might wish to target a larger sample or a larger number of trials in the priming experiment, since it is typically recommended to obtain 1600 readings per condition (Brysbaert & Stevens, 2018). The present study had 800 readings per experiment (32 trials / 4 cells $\times$ 50 participants $\times$ 2 experiments), suggesting that doubling the trials or the sample would be the rational next step.

The second obvious improvement is to increase the duration of the learning phase, or alternatively, the spacing of the exposure of the learning phase (e.g., over several sessions), to fortify the results (Dagenbach, Horst, & Carr, 1990; de Waard, Theeuwes, & Bogaerts, 2025). It may also be insightful to use performance metrics from the online game, such as error rates during learning, to examine whether such metrics are indicative of the learned sound associations.

The third improvement concerns the sounds used. In the present study, the two types of sound (percussive metallophone vs. bowed chordophone) may have been conceptually and acoustically too distinct to support both negative and positive connotations. The explicit task already suggested that the participants evaluations of the sounds did not significantly increase in valence ratings after the online game, although assumed decrease in valence ratings was observed. This suggests that making sounds more positive potentially requires either more exposure during the learning paradigm or alternatively the starting point of the sounds should be less pleasant. Using two more similar, potentially artificial sounds may better afford such connotations while avoiding familiarity and real-world associations.

Conclusion

We have shown first promising results in a game-based learning paradigm for online experiments that can be used to investigate the perceived valence of sounds. In general, the plasticity of perception with sounds has not been studied in detail despite some prior selected studies of elements of music using learning paradigms (e.g., Rohrmeier et al., 2011; Leung & Dean, 2018; Sarasso et al., 2021; Smit, Milne, Dean, & Weidemann, 2022). Perceptual learning has been documented in all sensory domains (Seitz & Dinse, 2007). However, the combination of explicit and implicit tasks tends to be used only infrequently (Szpiro, Burlingham, Simoncelli, & Carrasco, 2025), although these may reveal different underlying representations and remove unwanted biases in responses (Fazio & Olson, 2003).

Although further exploration is needed to optimise the paradigm to examine affective connotations, this approach could be fruitful for investigating the malleability of perception in a more general way. What are the general constraints of this learning? For instance, how much is the acquisition dependent on stimulus properties? To what extent does exposure (duration, intensity, repetition, multiple sessions) or rewards determine the strength of the acquired explicit and implicit associations? Finally, how is perceptual learning moderated by participant expertise, culture, and attention? Answering even some of these questions requires a large-scale online paradigm with sufficient numbers of participants to systematically address the aforementioned issues. For this reason, it is vital that the actual learning game is fun, adaptable, and accessible to various populations of participants. Developing a Flappy Bird clone or a similar easily adjustable and previously popular game in an open source framework may offer the required approach for scaling up such a research programme.

This study demonstrates the potential of gamified online paradigms for investigating perceptual learning of affective sound connotations, based on successful large-scale approaches in perception research (Woods, Velasco, Levitan, Wan, & Spence, 2015; Khaldi, Bouzidi, & Nader, 2023; Daniel, Kucherbaev, Cappiello, Benatallah, & Allahbakhsh, 2018), some including music perception abilities (Samiotis et al., 2021), or specific aspects of music processing such as oral transmission (Anglada-Tort, Harrison, Lee, & Jacoby, 2023), rhythm production tasks (Anglada-Tort, Harrison, & Jacoby, 2022), mood annotation of music (Lee et al., 2025) that support the viability of online approaches for addressing fundamental questions about perception.

Critical questions remain about the boundary conditions and mechanisms of perceptual learning: the role of stimulus properties, exposure parameters, individual expertise, and cultural factors in shaping affective associations. Answering these questions requires systematic investigation across large, diverse samples, which makes online paradigms methodologically essential rather than merely convenient. We advocate for the development of open-source, adaptable game frameworks that combine accessibility and participation with rigorous experimental design and longitudinal assessment. Such approaches can illuminate fundamental mechanisms underlying the malleability of music perception while enabling research at unprecedented scales.

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