# Remembering the forgetting curve: A simulation and new explanation of the inverted-U preference trajectory for exposure to music.

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## Abstract
This paper tests the validity of a novel function intended for automated music recommendation systems. The function uses repeated exposure information for a specific song in a music library and is based on a linear combination of Ebbinghaus forgetting curves. This linear combination produces an output for recommendation strength, termed freshness, which appears to encapsulate Berlyne's inverted-U model, having the effect of moderating exposures so that over-exposure is avoided. The function was tested using two simulations: one using fixed time increments between exposures, and the other using changing time increments between exposures. All simulations produced inverted-U trajectories. We therefore suggest that existing recommendation methods may benefit from the implementation of a parsimonious, inverted-U approach.

## Keywords
music preference, automated recommendation, exposure

## Aims
Music recommendation systems use a variety of methods intended to lure the user to a piece of music they are likely to wish to hear. These methods typically use similarity of features—such as audio content, metadata, user ratings, or demographic information—as their primary components for recommendation (Celma, 2010). While such similarity-based approaches

may suitable for the recommendation of mediums such as books, television shows and films in which consumption typically takes a minimum of several hours, if not days or weeks, music items can be consumed at a much quicker rate, and can at times involve successive, repeated listenings to the same item. As such, existing systems could better incorporate developments in the field of music psychology, such as those concerned with multiple exposures. We investigate a novel, potentially parsimonious realization of a psychologically plausible model of music preference. Our review of the literature identified one system, proposed by Hu and Ogihara (2011), that specifically incorporates elements concerned with successive exposures to music. The system in question contains a recommendation parameter referred to as freshness, which applies Ebbinghaus' (1913) forgetting curve of memory retention $R=e^{(-(t/S))}$, where $R$ is memory retention, $S$ is the relative strength of memory, and $t$ is time elapsed since the last exposure to the specific song. As time elapses, a song is more likely to be recommended due to its assumed increase in freshness. This system may therefore contain benefits in contextual recommendations to music over subsequent listenings. We additionally noted a potential similarity between a novel combination of forgetting curves and Berlyne's (1971) inverted-U model of preference, a well-established model for predicting preference. The model proposes that preference for a song will produce a more-or-less parabolic, inverted-U as a function of exposure. In this paper we report a discovery that by presenting the forgetting curve function in a particular way, we could reproduce the inverted-U curve. A recommendation system informed by the inverted-U in terms of exposure could recommend songs more regularly in early stages of familiarity, in order to push preference up towards the optimal point however these recommendations should become less frequent once the optimal point is reached (for details, see Chmiel & Schubert, 2017). The aim of the present study is to expand work by Hu and Ogihara to discover a simple function that is psychologically plausible and able to model the inverted-U trajectory.

## Methods

Our proposed function based on the forgetting curve presented as a linear combination is shown as $F(t,S) = e^{(-t/S)} - e^{(-t/(S-1))}$ in which $S$ represents an exposure event to a song in an individual's personal library (a positive integer), and in which $F$ is the ‘freshness' (according to Hu and Ogihara) or 'favor' for a song $k$ in a recommendation library. We tested the proposed $F$ function through simulations with all possible coefficients set to arbitrary unit values, and varying $t$ and $S$ values accordingly. Two sets of simulations are presented. The first contains fixed increments of $t$, simulating the controlled laboratory setting where the music stimulus is exposed repeatedly after a fixed amount of time. A range of simulations, from small through to larger increments were tested for each simulation. A second simulation was conducted in which increments of $t$ varied by different amounts: (1) increasing $t$ values between subsequent exposures, (2) decreasing $t$ values between subsequent exposures (until the timing between exposures becomes the same as the duration of the stimulus) and (3) random $t$ increments (providing a potentially more realistic simulation of 'actual' listening habits).

## Outcome(s)

The simulations are presented in Fig. 1 (set 1) and Fig. 2 (set 2). The first set of simulations demonstrates the clear emergence of the inverted-U curve for $F$, and so resemble preference responses predicted by the model. This pattern emerged regardless of the setting of the inter-stimulus time delay. For set 2, the inverted-U also emerged even when the time delays between exposures were not fixed. Polynomial curve fitting was applied to the three random inter-exposure time simulations, with the result producing an inverted-U trajectory in each case.

## Discussion

The simulation of the proposed model confirms that it is possible to represent the finding that preference is related to exposure to a piece of music as an inverted-U using a psychologically plausible mathematical model of memory retention. This suggests that mathematical-biological models can provide new insights into how the somewhat mystical views on music preference can be represented in an objective manner, and utilized for quantifiable predictions and testable hypotheses. Future work will endeavour to use empirical data to discover the coefficients of the model, for example, in the simplest form of $F(t,S) = \alpha(e^{(-t/S))} - e^{(-t/(S-1)})$ where $\alpha$ is the coefficient to be solved. The parsimony of the model also makes it a highly appealing candidate for sophisticated automated music recommendation systems that can track individual listening habits.

## References


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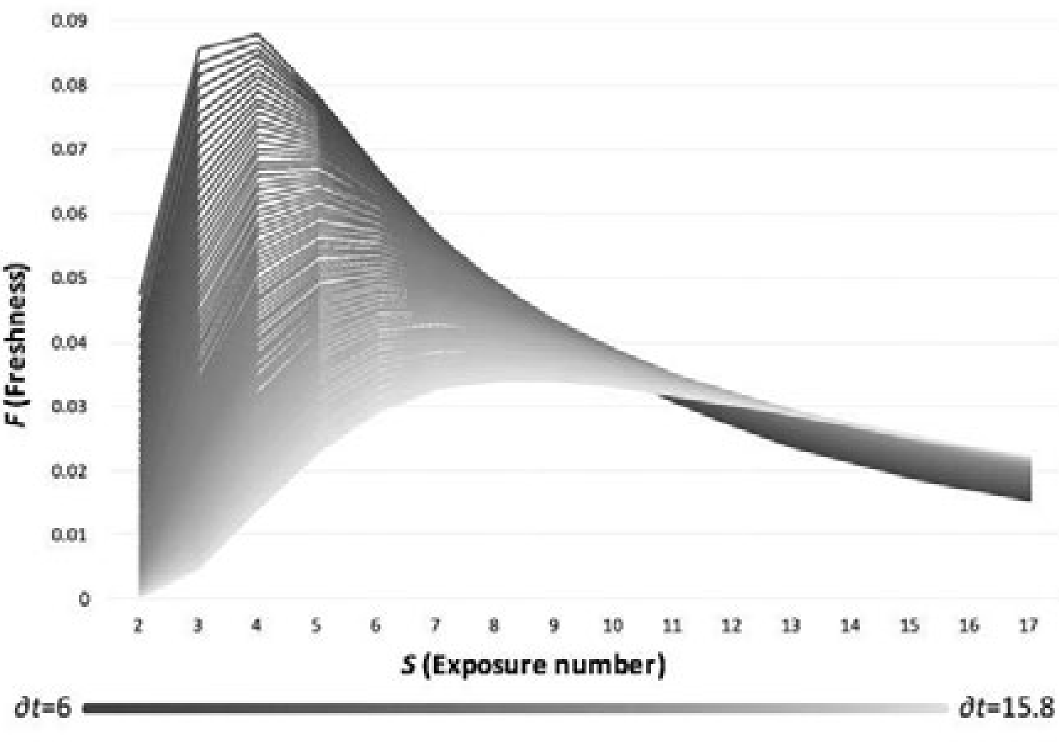


Figure 1: Plot of exposure-preference simulation with fixed interexposure time increments *(t)* incrementing by 0.1.

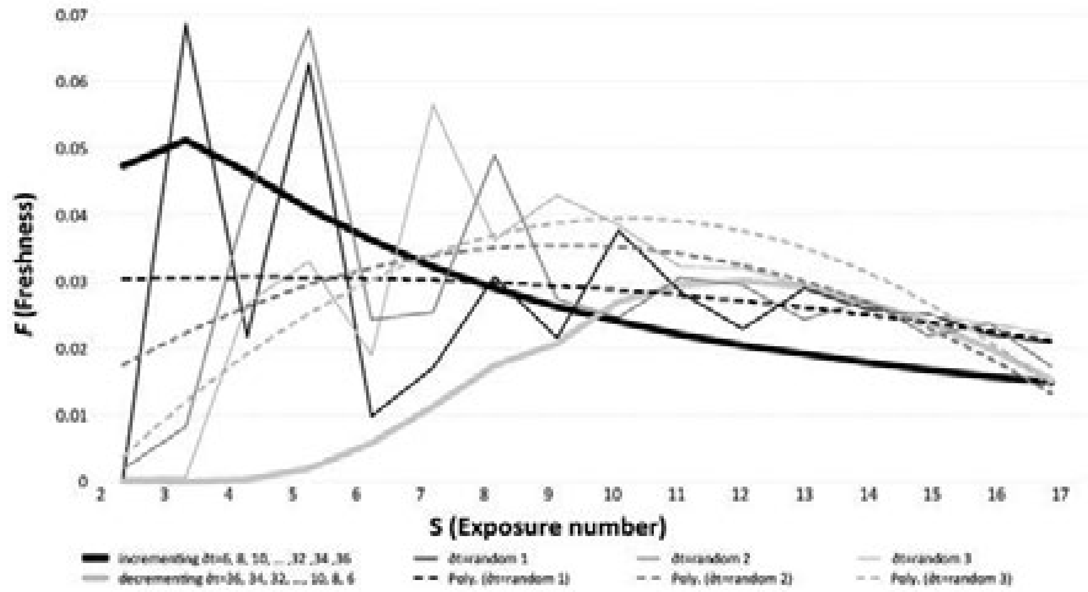


Figure 2: Plot of exposure-preference simulation with changing (incremented; decremented; random) interexposure time increments *(t)*. Polynomial curve fitting has been applied to the three simulations with random time increments (shown with dashed lines).