A simple algorithm for music recommendation, built on established psychological principles

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Abstract. This paper tests the validity of a novel proposal intended for automated music recommendation systems, based on repeated exposure information to the same stimulus contained in a music library. The proposed function is based on a linear combination of Ebbinghaus' *forgetting curves* which, we argue, produced Berlyne's *inverted-U model*. It has the effect of a stronger recommendation for a specific music library item after a moderate amount of exposure to that item, and therefore may aid in avoiding over-exposure. The function was tested using two sets of simulations: one set using fixed time increments between exposures, and the other using changing time increments between exposures. All simulations produced inverted-U trajectories, thereby providing evidence that the simple memory principle proposed by Ebbinghaus can be applied to music preference in a parsimonious way.

Keywords. Aesthetics, Automated music recommendation, Exposure, Music Preference

1 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 [1], [2]. While such similarity-based approaches may be 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. Therefore, existing systems could better incorporate developments in the field of music psychology, such as those concerned with multiple exposures. In the present work we investigate a novel, potentially parsimonious realization of a psychologically plausible model of music preference.

Our review of the literature on existing recommendation methods identified one system, proposed by Hu and Ogihara [3], 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' [4] *forgetting curve* of memory retention

$$R = e^{-\frac{t}{S}} \tag{1}$$

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. Ebbinghaus produced the forgetting curve from several experiments examining the relationship between memory retention and the amount of elapsed time-since-learning. The result was a decreasing logarithmic function. As such, Hu and Ogihara's freshness parameter is designed so that as more time elapses since a song was last played, that particular song becomes increasingly more likely to be recommended due to its assumed decrease in memory retention. The decrease in memory retention is, according to Hu and Ogihara, a factor that contributes to an *increase* in perceived freshness. Memory freshness, to use Hu and Ogihara's expression, can therefore be represented as the difference between memory retention for a song at time t_a and memory retention of the same song at a later time, t_b. We noted a perceptual similarity between this novel combination of forgetting curves and Berlyne's [5], [6] inverted-U model of preference—a well-established model for predicting preference—but we had not cited an explicit connection made in previous research between Berlyne's conceptual inverted-U and the 'freshness' effect that results from a combination of Ebbinghaus' exponential decay curves.

Berlyne's model proposes that preference for a song will produce a more-or-less parabolic, inverted-U as a function of exposure. Hypothetically, a recommendation system informed by the inverted-U in terms of exposure would recommend songs more regularly in early stages of familiarity, in order to push preference up towards the optimal point, however in an effort to avoid over-exposure these recommendations would become less frequent once the optimal point is reached [7]. Our review of the literature revealed no such existing systems. In response to this, we recently [8] proposed that by presenting the forgetting curve R (1) as a linear combination, we could reproduce the entire inverted-U curve, specifically as the function F shown as

$$F(t,S) = e^{-\frac{t}{S}} - e^{-\frac{t}{(S-1)}} \tag{2}$$

in which S represents an exposure event to a song in an individual's personal music library (a positive integer), and in which F is the 'freshness' or 'favor' (both terms proposed by Hu and Ogihara) for a song k in a recommendation library. This representation will be the same as the characterisation reported above, but instead of substituting for t_a and t_b, we set

$$t = t_b - t_a \tag{3}$$

and treat the current exposure number (the number of times the song from the listener's library would be played to the listener, if it were selected for playing 'now') as S. The proposed function (2) is intended as an expansion on the work by Hu and Ogihara, and appears to produce a simple function that is psychologically plausible and able to model the inverted-U trajectory. This study aims to test the above function (2) through a number of trajectory simulations.

2 Method

In the present study we test the proposed *F* function (2) through a number of simulations with all possible coefficients set to arbitrary unit values, and varying *t* (time) and *S* (exposure number) accordingly. The study consisted of plotting the function under various conditions, specifically by manipulating values of *S* and *t*. Function values and plots were generated using *Microsoft Excel*. We retained the simplest form of the function, without any general coefficients; all multipliers were set to 1, exactly in the form shown in (2). Two sets of simulations are presented, with each set containing a number of individual simulations containing 16 exposures. The first set 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 set; increments ranged from 6 to 15.8. A second set was conducted in which increments of *t* varied by different amounts, as listed below

1) Increasing *t* values between subsequent exposures. Time increment (∂t) values increased from 6 to 21.
2) Decreasing *t* values between subsequent exposures, until the timing between exposures became the same as the duration of the stimulus. Time increment (∂t) values decreased from 21 to 6.
3) Random time increments, providing a potentially more realistic simulation of 'actual' listening habits. Random time increment (∂t) values were created through *Microsoft Excel* RANDBETWEEN function, ranging from 6.6 to 24.7.

3 Outcomes and discussion

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 resembles preference responses predicted by the model. This pattern emerged regardless of the setting of the inter-stimulus time delay. It is important to note that while each curve in Fig. 1 produces an inverted-U trajectory, the shape of the inverted-U curve is determined by the inter-exposure *t* values as exposure *S* is incremented. The curve shown as the lowest value of ∂t (6, the top, blue curve in Fig. 1) outlines a relatively sharp increase, peaking around the fourth exposure, and a sharp subsequent decrease. In comparison, the curve containing the highest shown value of ∂t (15.8, the bottom, grey curve in Fig. 1, indicating a relatively large time gap between each exposure) outlines a comparatively shallow increase, peaking around the eighth exposure. The subsequent decrease for this trajectory is also comparatively gradual compared to curves with lower values of ∂t. Therefore, the present function is able to demonstrate the fluidity and subtleties of the effects of different time delays, which previous characterizations of Berlyne's model have failed to do. Rather, the present function appears to encapsulate theoretical predictions of preference for distributed exposures voiced by Martindale [9].

For set 2 an underlying inverted-U also emerged, even when the time delays between exposures were not fixed. Three simulations of random time spacings between exposures are shown as solid lines in Fig. 2, simulating uncontrolled exposures, perhaps more realistic than the equal time spacing between exposures of set 1 that are more likely to be found only in laboratory conditions. Polynomial curve fitting was applied to the three random inter-exposure time simulations, with the result producing an overall inverted-U trajectory in each case (see dashed curves in Fig. 2). Additionally, we can compare the non-polynomial trajectories of the random simulations to previous results reported in the literature. For interest, set 2 also included a gradually increasing time delay between exposures (solid orange line in Fig. 2), again, each producing clear inverted-U trajectories with subtly changed forms that may reflect a psychological characteristic. While Berlyne's theory

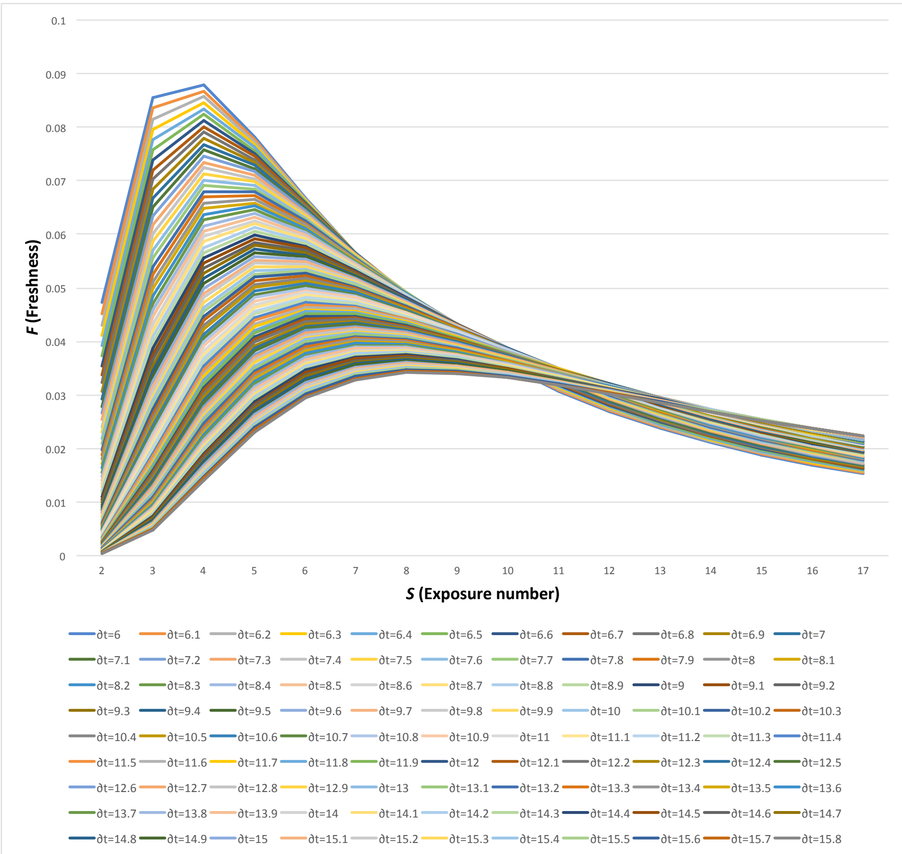

Fig. 1. Plot of freshness function (F) varying by exposure for fixed time increments ∂t.

could be interpreted as predicting a smooth and even parabolic function between preference and exposure, this is not necessarily the case. The model simply suggests that a moderate number of exposures will generally tend to produce the putative, optimal point of preference; additional smaller fluctuations in the trajectory do not counter this prediction. Indeed, the fluctuations of these non-polynomial random trajectories in Fig. 2 may be the most accurate representation of the inverted-U function between preference and exposure that has been observed in the reported data, e.g. [10]-[13]. The simulations containing random time increments could therefore be argued as being the most ecologically realistic in terms of how we tend to listen to and respond to music on an everyday basis.

4 Conclusion

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 function using a psychologically plausible 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 endeavor to use empirical data to discover the coefficients of the model, for example in the simplest form of

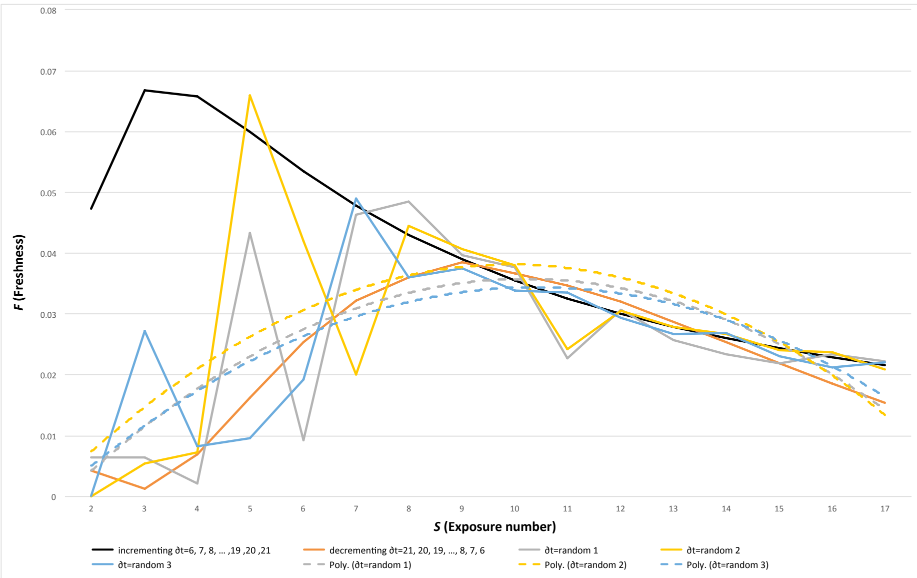

Fig. 2. Plot of freshness function (F) varying by exposure S with changing inter-exposure time increments ∂t (incremented; decremented; random). Polynomial curve fitting has been applied to the three simulations with random time increments (polynomial fitting shown with dashed lines).

$$F(t,S) = \alpha(e^{-\frac{t}{S}} - e^{-\frac{t}{(S-1)}}) \quad (4)$$

where α 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.

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