A New Look at Musical Expectancy: The Veridical Versus the General in the Mental Organization of Music

Emery Schubert[1(✉)] and Marcus Pearce[2]

[1] Empirical Musicology Laboratory, The University of New South Wales, Kensington, Australia
e.schubert@unsw.edu.au
[2] Queen Mary, University of London, London, UK
marcus.pearce@qmul.ac.uk

Abstract. This paper takes a step back from what we label 'problem solving' approaches to the psychology of music memory and processing. In contrast with generalised expectation theories of music processing, a hypothesis is proposed which is based on the idea that mental representations of music are largely based on a large library of individual pieces: Case-based memory. We argue that it is the activation of these memories that forms the critical aspect of musical experience. Furthermore, a specific hypothesis is proposed that it is possible to represent any new piece of music through the chaining together of different, pre-existing veridical segments of music, in contrast with 'problem solving by generalization' which determines expectation based on statistical/stylistic/schematic factors. By adjusting segment length, or by forming new segments through repeated listenings, new music can be absorbed into an existing, growing mental database by chaining together existing veridical segments that match the incoming stimulus.

Keywords: Music processing · Veridical memory · Schematic expectation · Exemplars · Prototypes, musical experience, problem solving, spreading activation

1 Introduction

Current, established theories of music perception tell us that when we perceive music, the music signal is compared against certain principles and processes which lead to particular expectations. These expectations are then compared with the actual incoming signal and so the incoming signal is either processed as being a violation (generating, for example, surprise) or fulfillment of the expectation. Schema theory is an example of such an established perspective. Schema theory posits that through much previous

This paper is based on Schubert, E., & Pearce, M. (2015). Veridical Chaining: A case-based memory matching approach to the mental organization of music. In M. Aramaki, R. Kronland-Martinet & S. Ystad & (Eds.), 11th International Symposium on Computer Music Multidisciplinary Research (CMMR) (pp. 428–440).

R. Kronland-Martinet et al. (Eds.): CMMR 2015, LNCS 9617, pp. 358–370, 2016.
DOI: 10.1007/978-3-319-46282-0_23

exposure, regularities in the 'way that music tends to go' are formed. For example, when a melody reaches the seventh scale degree there is an expectation that the note which follows will be the eighth scale degree. Such an approach to music perception sees musical processing as a problem solving task, with the problem being to determine whether the music fulfills or does not fulfill (or partially fulfills) expectation. Bhuracha [1–4] among others has drawn our attention to another way in which expectation is assessed, namely through comparison with the veridical. That is, when listening to a well known tune, upon listening to the n^{th} note of the tune the next note (n + 1) that is expected is the next note of the tune itself, and this will not necessarily be the statistically more likely note that schema theory predicts. We can think of this as 'case-based' matching to distinguish it from the general, emergent rules of schema theory. Whether note n + 1 violates a schematically driven expectation or not, the veridical expectation will always follow the specific case stored in memory, what we will refer to as the 'mental representation' of the tune (or music).

While veridical and schematic expectancy are both fairly well understood phenomena, schema and other 'problem solving by generalization' (PSBG) theories have occupied the bulk of research attention on the mental organization of music. This is reflected in the computational models of music, which can consist of training a programming architecture, such as a neural network, with a music corpus, and then testing how the network deals with a new stimulus [e.g. 5–9]. For example, statistical analysis of note-to-note transition is one computational way of estimating expectancy. High note-to-note pitch transition probability that emerges in the test corpus (because of frequent occurrence) will mean that in the typical test piece the recurrence of that transition will be highly expected. This is why note-to-note transition probabilities are an example of PSBG theory.

Veridical expectation receives understandably less attention in computational modeling of music because the output decision-making is trivial. If a known piece is being processed, its veridical memory at any point, such as note n, provides a 100 % accurate prediction of what is expected at the next note (n + 1) of that piece. And if the incoming signal *is* that piece, there will be a perfect match, with complete expectancy fulfilled. Any perceived departure from the individual piece will be a 'perfect' mismatch from the veridically stored version. Expressive variation, embellishment, error and musical variation is considered later in this paper, but for now we consider veridicality in a strict sense, as though a precisely repeatable sound-recording.

Computational modeling of schematic expectancy presents interesting challenges in both computer science and music psychology. Such computational models provide a workspace where a large corpus generates a particular kind of complex, non-linear behavior, particularly where a musical progression presents an ambiguous set of possibilities, and the solution (e.g. determining the next note) is not well defined.

Despite the apparent triviality, veridical expectancy *is* subjected to statistical analysis. Some researchers have investigated how long it takes (usually in terms of time or as a function of number of notes) before the listener is certain of the identity of a particular unfolding melody. For example, Huron [10, pp. 221–224] played a set of notes that made up a sequence of a familiar tune. Huron wanted to know how many notes were required before the participant was confident about the identity of the tune. The sequence of notes presented commenced with the first note only in one trial, the first two notes in another trial and so on. For each trial, within each familiar stimulus, the proportion of participants who could correctly identify the melody was calculated. Of the four excerpts reported, more than 50 % of participants identified the 'correct' melody by the fourth note in three out of the four pieces tested. The length of the sequence required for recognition of the familiar melody is a function of several variables; It is not a universal 'four notes' principle. Obviously the individual's personal familiarity with the actual piece is critical. But also critical is how many other tunes share the pattern. Huron refers to two pieces in particular, where the opening notes are identical in terms of tone-rhythm pattern: *O Christmas Tree* (*O Tannenbaum*) and *Here Comes the Bride*. Up to the onset of the fourth note, the tone-rhythm pattern is identical for each (assuming they are transposed to the same key). Greater than 50 % correct identification was reported after three notes for *Here Comes the Bride* and after five notes for *O Christmas Tree*. While it may seem strange that such high confidence could be reported for the first three notes of Here Comes the Bride even though the tone-rhythm pattern is still identical to O Christmas Tree, the metric accent, and other musical feature variables provide additional cues that help to distinguish the pieces (a matter to which we will return).

Nevertheless, the point is that after the presentation of a certain amount of information a veridical mental representation is 'primed'. Once the recognition reaches 100 % the computational question becomes less interesting because the 'problem' (of what is the next most likely note) has been solved for each subsequent note. That is, as per another stimulus used by Huron in the study, after hearing the semiquaver (sixteenth note) sequence E5, D#5, E5, D#5, E5, B4 with a piano timbre, the listener familiar with the piece will then expect the specific piece, or case, of Beethoven's *Fur Elise*. And as long as that is what the listener continues to hear, the expectancy will be perfectly predicted by the veridically encoded mental representation.

2 Veridical Processing Is Ordinary

The veridical matching of incoming stimulus with memory is a very normal, day-to-day kind of processing. In fact, it is an essential part of consciousness and identity. We know who we are and where we are because we recognize specific instances of our home, furniture, foods we eat, clothes we wear, Uncle Ling who lives down the road, the path we take to go to the park, school or work, and so on. Although humans have an astounding ability to process new situations based on previous information, the veridical, exemplar, case-based memory is fundamentally important, too. And the two ways of processing need not be mutually exclusive.

In the case of music, a typical individual raised in Western culture has a high level of familiarity with a large mental library of individual pieces from at least their adolescence [11, 12], and like aspects of everyday life, this familiarity plays in important role in forming one's identity [e.g. 13, 14]. Huron even claims that "[m]ore than 99 % of all listening experiences involve listening to musical passages that the listener has heard before" [10, p. 241]. With such prevalence of familiarity with individual musical cases, as distinct from general principles of how music unfolds, it surprising that apart from the work of a few, such as Bharucha and Huron—both cited above, more attention is not paid to the processing of veridical musical information and its fundamental role in the mental organization of music.

If the announcer on a radio station says that the next piece is Beethoven's *Fifth Symphony*, the Beatles' *Penny Lane*, Dave Brubeck's, *Take Five*, Danny Elfman's *The Simpsons Main Title Theme*, Nirvana's *Smells Like Teen Spirit, Happy Birthday* or *Twinkle Twinkle Little Star*, then those familiar with the piece will have an expectation of what is about to come [for more detailed discussion, see 10]. And unless the presenter made an error or was joking, or if the listener had to stop listening, the expectation will be fulfilled. Even the announcement of the piece may initiate a mental rehearing, before the first note is sounded (as may well be the case now for the reader for one of the above examples). Furthermore, even without the announcement, the first few seconds, and even less [15–17] can be enough to initiate the expectation of what is to come – the actual music piece itself.

In this paper, we will argue that closer analysis of how veridical data is organized mentally will give insight into (1) the nature of musical experience and (2) how musical memories may be organized in a way that contrasts with PSBG theories. As an alternative to PSBG theories, we will build on a 'case-based memory matching' theory of music from which we present the 'veridical chaining' hypothesis of musical organization [18]. To simplify the examples we will refer largely to tone-rhythm pattern coding. But the discussion applies to all aspects of music, including rhythm, timbre, timing and loudness. Timbre and timing are important factors too, but tone-rhythm is easier to use for illustrative purposes through the convenience of Western music notation.

3 Musical Problem Solving or Musical Experience?

While schema theory and other theories applying a PSBG approach have made great strides in understanding how the mind processes music, the assumption or inference that music listening is a problem-solving task has some limitations. It suggests, and in many theories explicitly states, that the comparison of an incoming piece against a generalized prediction is what generates the aesthetic or affective experience, making the prediction process fundamentally important [19]. Perhaps the most well known instance of this perspective is Meyer's theory of expectancy in which he argued that "[e]motion or affect is aroused when a tendency to respond is arrested or inhibited" [20, p. 14]. In contrast, author ES has argued elsewhere that the activation of mental representation generates affect [21–23]. The idea is based on Martindale [24–27], where the activation of cognitive units generates pleasure [for more detailed discussion, see 21, 22, 28, 29]. The point of this approach that is in sharp contrast to (though not mutually exclusive from) PSBG theories is that the pleasure in response, or attraction we have, to music is not a result of (necessarily) a result of the problem solving process, but the mere activation of (existing) mental representations. 'Affect through activation', as it may be thought of, makes the role of veridical storage and activation critical to musical experience, and therefore to the music listening experience. This is in concert with the view of Stephen Davies who near the opening of his book on *Musical Meaning and Emotion* states:

> I do not believe music is a symbol system that conveys a semantic meaning, or quasi-semantic meaning, content. But I am not embarrassed to use the term "meaning" here because I think both that music can and should be understood to be appreciated and that it is created to be so. That composers intend to make something that invites attention, engagement, and consideration rather than aiming to stimulate mindless reflex, and that they succeed in producing works rewarding in just this way, suggest to be that we might reasonably talk of music's meaning what is grasped by the person who understands it. [30, p. ix]

If the role of veridical activation is crucial to musical experience, we can reconceptualise our understanding of the mental organization of music. In what follows, such an reconceptualisation is proposed.

4 Case-Based Memory (CBM) Matching

As a point of departure from PSBG theories of music processing, we will use case-based memory [31] matching as a starting point of hypothesizing how music is organized in memory. Case-based memory is an outgrowth of the Script theory which focuses on the role of procedural knowledge in problem solving in psychology and artificial intelligence research [32–35]. It is more commonly referred to as case-based 'reasoning' [34, 35] but in this paper we use of the term 'memory' deliberately because of our emphasis on activation (of memory) rather than problem solving. Consider an approach to computational language translation of natural language text (e.g. from English to Cantonese) called translation memory [36]. This is a text translation system that accesses large databases of text, and finds the closest match to the target text. If one or more exact matches are found, the target text in the corresponding rows of the database are retrieved. If a match is not found, the next best match is selected, if available, and further processing takes place before a possible solution is found. Immediately, in this example, it is clear that text translation *is* a problem solving task. And while we have argued above that music is primarily a mental activity, rather than problem solving task, the simple computational example of translation memory is still informative. In music, the process of finding and activating the match is in itself sufficient to initiate a musical experience. Returning to the discussion of Huron's veridical memory recognition task, consider now the melody in Fig. 1 in quadruple meter.

Those who are able to imagine the three note melody may instantly start thinking about the song *Yesterday* by Lennon and McCartney. We may even start hearing the next notes of the melody as shown in Fig. 2. In fact, we may even hear the guitar timbres, and McCartney's voice, as we imagine the piece triggered by the three notes of Fig. 1. This is an explicit example of veridical activation. It is achieved by having a 'perfect' match from a segment of the incoming music (as decoded from a music score

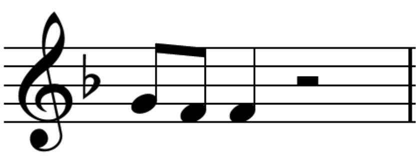

Fig. 1. Opening notes of a well-known tune.

Fig. 2. A possible continuation of the melody in Fig. 1.

in this case) with memory store. It can therefore be thought of as direct memory addressing that is fundamental to memory organization in microprocessors and the translation memory approach. The returned data are the next notes in the sequence, and in fact the piece itself. In the case of translation memory it is the translated text. There is no need for recourse to PSBG of expectation. We do not need to look at note-to-note transition probabilities. Expectation and implication theories argue that when a PSBG outcome is not achieved, surprise results. CBM, on the other hand, predicts that any digression from the veridical will be unexpected. But importantly, if the digression has not been previously encoded, it will not be perceived as a musical experience because no activation takes place at the point [see also 29].

The activation of the memory that matches with the musical extract is linked to other, previously encoded data. These data can be classified into two broad kinds: intramusical and extramusical [20, 37]. Extramusical links refer to activation of representations consisting of connections outside the music itself, such as thoughts, situations, images, designations, ideas as so on [see, for example 12, 38, 39, Chapter 8]. Intramusical connections are those made to other musical segments, both within the piece being sounded (intraopus) and to other pieces (extraopus) [40]. All of these links can be activated through the principle of spreading activation [41, 42], and the repeated activation of these links binds them together into new veridical stores [e.g. 43].

Of interest here is the activation of the intraopus links. Just as with the lookup table pertaining to the translation memory discussed above, the returned value from the intraopus perspective is the next note or group of notes. That is, the next contiguously coded 'fragment' becomes primed (we could also say 'expected'), and then when that fragment of music is sounded, it acts as the index for priming the next contiguous segment after that one, and so on, recursively. If we take our starting point as recursive activation of a memory as a result of the temporally unfolding, continuing matches with the sounded music, we are able to generate hypotheses about how new pieces of music may be processed, putting aside (for now) the PSBG approaches. One hypothesis which we now discuss consists of online segmentation of the incoming piece in such a way that matches for each segment can be found, and then chained together.

5 Veridical Chaining

When a new piece of music is auditioned, our mental network will try to find a match with an existing representation. If a match is not found, the incoming musical stream will be broken into smaller segments until a match is found. Note that, for now, we are avoiding reference to statistically 'best', 'approximate', 'similar' or 'nearest neighbour' match which are hallmarks of PSBG approaches. The match, for the purpose of the current hypothesis, must be 'exact'. In the case of a tone-rhythm pattern, a downward segmenting size adjustment of the incoming stream continues until some match is found, or until the segments become too small to process. In the case of no matching segments, the stimulus (or that part of it) will not activate a mental representation. With sufficient repetition, however, a new mental representation will form: a representation of the new segment or piece, commensurate with the principle of mere exposure [44, 45].

If a particular segment *has* been encoded previously, that pre-encoded segment will be activated, and activation will also prime segments to which it was previously linked. If, on the other hand, there is no match, there will be no phenomenal recognition or 'sounds like' or 'ah, I know this piece' experience.

As a simple example, suppose a new piece of music consists of two segments (for example, two phrases of music) and each segment has a unique but non-overlapping match in the existing memory (mental representation) network. That is, if a short piece of familiar music can be described as consisting of two phrase sequences, say AB, and another familiar piece as XY, then a new piece consisting of AY will be easily encoded because of its matches with the two previously distinct pieces, but will activate the mental representations of both those pieces. The process is dynamic and interactive, and so all represented stimuli containing some segmental match can be affected by the intrusion of the new piece. This is the basic groundwork which presents an alternative to PSBG, and can be summarized as *veridical segment cross-chaining of existing mental representation segments*, or for ease of reading, 'veridical chaining' [18]. In the example, over time, with further exposure, a new link forms connecting the pre-existing segment A with the pre-existing segment Y. When well learnt, the auditioning of segment A will prime both segments B and Y, since there are links to both through the chaining process.

Consider *Twinkle Twinkle Little Star* (TTLS) and *Baa Baa Black Sheep* (BBBS). Ignoring the words and transposing into the same key, each melody will activate the same segment in the opening bar. For the purpose of understanding veridical chaining, let's make the assumption that the listener whose mental network we are investigating has only encoded one piece of music in autobiographical time, and that she has heard the piece sufficiently frequently to have a mental representation of the piece. The mental representation is shown in Fig. 3 in Western musical notation for convenience. Suppose now that the individual is exposed to the tune in Fig. 4.

Under the assumption of case-based memory matching, the first bar will present a perfect match, and therefore activate the mentally represented first bar. However, during this time, the second bar will become primed and therefore expected, assuming that the listener has (incorrectly) recognized the tune as TTLS. When the second bar actually begins sounding there will no longer be a case-based match. Again, we must emphasize that we are taking an 'extreme', veridical perspective. It is obvious to us that the quaver (quarter note) pattern in the second bar of BBBS is an embellishment of the

Fig. 3. Opening four bars for the melody of *Twinkle Twinkle Little Star*.

Fig. 4. Opening four bars for the melody of *Baa Baa Black Sheep*.

same point in TTLS. But for the purpose of illustration, and on the basis that only 'perfect' matches are possible, similarity is not enough. A 'perfect' match is the requirement.

The way the network will process the new piece according to case-based memory matching is illustrated in Fig. 5. Strictly speaking, the hypothetical individual who only has one piece stored in memory will have that piece primed as soon as the first note is heard (because there is only one solution after hearing one note). The illustration however shows that it takes three 'steps' (notes) to be sounded before the individual 'recognises' (and hence activates) a mental representation (time steps 3 to 5). This is to keep the process more in line with the findings reported by Huron, discussed earlier. But the specifics are not so important here. The important point in the hypothetical example occurs at time step 6, where the melody ceases to (perfectly) match that stored in memory. At that point, no activation is taking place, although some residual priming may remain for the representation of the initially primed piece.

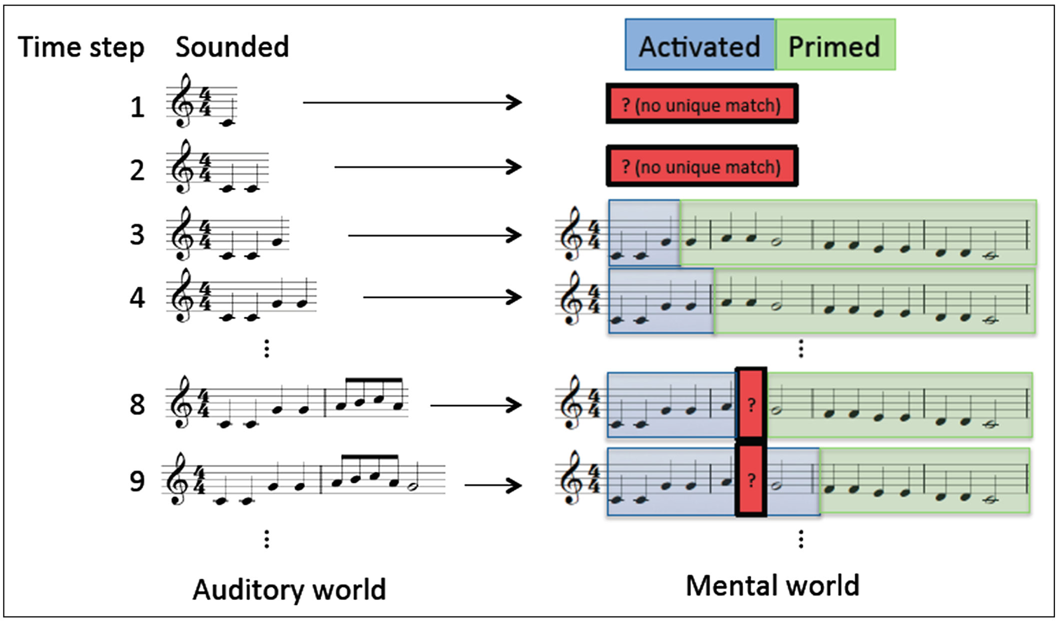

Fig. 5. Case-based memory matching for a new, incoming piece (BBBS) when the only available veridical memory is TTLS. Blue shading indicates activated mental representation. Green shading indicates mental representation primed as a result of the activated mental representation. Red shading indicates a mismatch – no activation. The hypothetical individual has only one piece of music in memory, meaning that the opening notes (time steps 1 and 2) will match TTLS. No 'unique' match indicates the more general case when the individual has more pieces mentally represented. Time steps are in units of unfolding notes. (Color figure online)

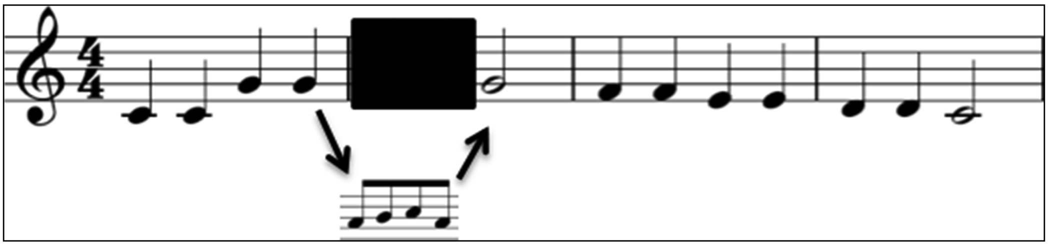

Fig. 6. Example of a veridical chain formed using an existing representation of a previously known piece, and the linking to a segment that diverged (had no match) from the original. The new piece is heard sufficiently frequently and this leads to the chaining of the links to form a new, veridical mental representation.

If we now suppose that the individual becomes frequently exposed to BBBS, then the TTLS network will still be utilized, but eventually a new segment will form, consisting of the quaver passage. The new passage is accessed by a link from the first bar of TTLS, and then, after the activation of the new segment, a link will return and continue the activation of the remainder of TTLS, as shown in Fig. 6. The 'chaining' together of old segments in the processing of new, incoming music, is the basis of the veridical chaining hypothesis.

As the individual hears more and more pieces of music, more and more mental representations are developed. An extreme interpretation of veridical chaining is that the music will always be parsed so that there are matches with an existing mental representation or portions thereof, and if no representation is available, no activation takes place. If there is no match regardless of segment length, repeated listening is necessary to form a new mental representation of that segment. As the mental database becomes large enough, there will be more and more opportunity for new pieces to generate links across different segments of pre-existing memories simply because there are more to choose from. Eventually, the matching of segments, such as the first three of four notes reported in the study conducted by Huron, will open up a vast range of possibilities, because so many notes will contain those segments. The extreme view is that there is no need to find a solution that is similar in the sense of PSBG, should an exact match not be found. But on the other hand, once a segment becomes small enough, it is very likely that an exact match can be found, just not a unique solution. It is at this point that veridical segmentation melds with many PSBG models because numerous, minute combinations of veridical segments are able to give the appearance of schematic or generalized principles. This can be demonstrated through the calculus principles of limiting sums and integration [e.g. 46].

Recent PSBG approaches use probabilistic models that store a complete record of every musical sequence ever experienced [49]. This is achieved efficiently using suffix tree representations [49–52]. In these models, new musical sequences are matched with previously heard sequences by following the appropriate transition in the suffix tree as each consecutive note is heard. Expectations are generated probabilistically through analysis of the frequency with which different notes have followed the context in the model's previous experience. When they encounter a context that has not been heard before, these models generalize by generating expectations using a shorter suffix of that context that have not been heard before. Therefore, such models may prove capable of integrating veridical chaining with PSBG, since they store veridical representations of every musical sequence experienced but also generate schematic expectations by generalizing to lower-order contexts. This is an important topic to be developed in future research.

We conclude this section by noting that it has been established in the literature for some time [e.g. 47] that when a prototype representation is established, the individual exemplars related to that prototype are also activated, and the degree to which either an exemplar versus a generalized prototype can be activated is a matter of some debate. For example, some research has suggested that when our mental database is large enough, activation of an exemplar is a more efficient way of identifying the category to which the stimulus belongs than is the prototype [48]. The role of the exemplar, or the veridical, in psychological perception is therefore difficult to ignore in cognitive science in general.

6 Evidence for Veridical Chaining

While evidence for veridical chaining is drawn mainly from script, prototype and case-based reasoning theory, there have been few studies in music perception that directly test case-based (veridical) memory coding, and the segmenting of a music stream. Two possible exceptions are briefly outlined here. Justus and Bharucha [53] compared responses to mistuned versus in-tune final chords after being primed with a schematically probable chord, or a schematically improbable chord. Relatively fast, accurate response in identifying the mistuned chord in the harmonically close chord target condition versus distant chord target was taken as evidence that schematic processing is favoured over veridical. The veridical condition had each trial consisting of a 'preview' prime-target followed by the trial prime-target pair, but in the trial the target on the second occasion might be in tune or out of tune—that is, congruent or incongruent with the first pair.

Similar results were reported by Tillmann and Bigand [54], with schematic expectancy better explaining faster and more accurate responses. The researchers used chord sequences, with manipulation of the final chord while participants performed a timbre judgement task on the final chord. Exposition phases were manipulated with the goal of generating schematic (Experiment 1) and veridical (Experiment 2) mental organization of chord sequence materials.

These studies, and others, generally assume that veridical coding can be achieved by a fairly short period of repeated exposure. However, veridical memories of the kind we have been discussing are all firmly established in long term memory, and may well consist of exposure over several days, weeks and years. Hence it may be wise to distinguish between 'long term veridical memory' and 'short term veridical memory', the latter being more convenient and pragmatic to test under well-controlled experimental conditions. In the Tillman and Bigand study, when the group was trained with harmonically related material (prior to test trials), they were overall faster. Perhaps one measure in their design that could have demonstrated 'long-term' veridical coding would be if reaction time for the repeated exposure group had reached the same level as the group receiving unrelated, but similar (generalized) examples, where a schematic coding may emerge – short term schematic preparation. That is, the repetition phase would need to be extended until this condition was met (an experimentally problematic design). Another alternative would be to retest recognition of items from the exposure phase, but do so at a much later time (weeks or months later) to determine if the pieces had indeed formed a long lasting veridical memory, and hence, mental representation. In other words, we have not cited a study where *long-term* veridical memory generated expectancy has been tested on an equal footing with schematically generated expectancy. The veridical chaining hypothesis presents one impetus for designing such a study.

7 Conclusion

This paper presented the view that the activation of musical exemplars *is* the fundamental act of the musical experience, and that veridical chaining allows this simple principle to be retained. We do not want to dogmatically replace or denigrate PSBG approaches. But we do want to point out that case-based memory matching, and the veridical chaining hypothesis shifts the focus of understanding musical experience to the 'act of activation', rather than problem solving. In this regard, veridical chaining plays an important role in questioning the implied or inferred aspects of music processing that are now considered mainstream in music psychology and computational modeling of music perception. Our provocative angle here is that if a stream of incoming music is processed, why would it not first 'match' (activate) a previously encoded instance of itself? A sound recording should be able to do this because each replay of that recording is essentially identical, and so matching with the memory of the individual who has 'grown up' (*vis-à-vis* long term veridical memory) with that recording. The veridical chaining hypothesis will be expanded in the future. The aim of this paper was to introduce the principle of veridical chaining as an alternative to PSBG explanations of music processing and highlight its potential utility.

Acknowledgments. This research was supported by a Fellowship from the Australian Research Council (FT120100053) held by author ES.

References

1. Bharucha, J., Curtis, M., Paroo, K.: Varieties of musical experience. Cognition **100**, 131–172 (2006)
2. Bharucha, J.J.: Tonality and expectation. In: Aiello, R., Sloboda, J.A. (eds.) Musical Perceptions, pp. 213–239. Oxford University Press, London (1994)
3. Bharucha, J.J., Todd, P.M.: Modeling the perception of tonal structure with neural nets. Comput. Music J. **13**, 44–53 (1989)
4. Bharucha, J.J.: Music cognition and perceptual facilitation: a connectionist framework. Music Percept. **5**, 1–30 (1987)
5. Pearce, M.T., Wiggins, G.A.: Improved methods for statistical modelling of monophonic music. J. New Music Res. **33**, 367–385 (2004)

6. Pearce, M.T., Wiggins, G.A.: Expectation in melody: the influence of context and learning. Music Percept. **23**, 377–405 (2006)
7. Wiggins, G.A., Pearce, M.T., Müllensiefen, D.: Computational modelling of music cognition and musical creativity. In: Dean, R. (ed.) Oxford Handbook of Computer Music and Digital Sound Culture, pp. 383–420. Oxford University Press, Oxford (2009)
8. Temperley, D.: The Cognition of Basic Musical Structures. MIT Press, Cambridge (2001)
9. Temperley, D.: A probabilistic model of melody perception. Cogn. Sci. **32**, 418–444 (2008)
10. Huron, D.: Sweet Anticipation: Music and the Psychology of Expectation. MIT Press, Cambridge (2006)
11. Folkestad, G.: Digital tools and discourse in music: the ecology of composition. In: Hargreaves, D.J., Miell, D.E., MacDonald, R.A.R. (eds.) Musical Imaginations, pp. 193–205. Oxford University Press, Oxford (2012)
12. Hargreaves, D.J.: Musical imagination: perception and production, beauty and creativity. Psychol. Music **40**, 539–557 (2012)
13. MacDonald, R.A., Hargreaves, D.J., Miell, D.: Musical identities. In: Hallam, S., Cross, I., Thaut, M. (eds.) The Oxford Handbook of Music Psychology, pp. 462–470. Oxford University Press, Oxford (2009)
14. Lamont, A.: Musical identities and the school environment. In: MacDonald, R.A.R., Hargreaves, D.J., Miell, D. (eds.) Musical Identities, pp. 41–59. Oxford University Press, Oxford, UK (2002)
15. Gjerdingen, R.O., Perrott, D.: Scanning the dial: the rapid recognition of music genres. J. New Music Res. **37**, 93–100 (2008)
16. Plazak, J., Huron, D.: The first three seconds. Musicae Sci. **15**, 29–44 (2011)
17. Schellenberg, E.G., Iverson, P., Mckinnon, M.C.: Name that tune: identifying popular recordings from brief excerpts. Psychon. Bull. Rev. **6**, 641–646 (1999)
18. Schubert, E.: Reconsidering expectancy and implication in music: the veridical chaining hypothesis. In: Ginsborg, J., Lamont, A. (eds.) Ninth Triennial Conference of the European Society for the Cognitive Sciences of Music, RNCM, Manchester, UK (2015)
19. Narmour, E.: The top-down and bottom-up systems of musical implication: building on Meyer's theory of emotional syntax. Music Percept. **9**, 1–26 (1991)
20. Meyer, L.B.: Emotion and Meaning in Music. University of Chicago Press, Chicago (1956)
21. Schubert, E.: Enjoyment of negative emotions in music: an associative network explanation. Psychol. Music **24**, 18–28 (1996)
22. Schubert, E.: Loved music can make a listener feel negative emotions. Musicae Sci. **17**, 11–26 (2013)
23. Schubert, E., North, A.C., Hargreaves, D.J.: Toward a theory of music aesthetics: the affect-space framework. Psychology of Aesthetics, Creativity, and the Arts (submitted)
24. Martindale, C., Moore, K.: Priming, prototypicality, and preference. J. Exp. Psychol. Hum. Percept. Perform. **14**, 661–670 (1988)
25. Martindale, C.: Aesthetics, psychobiology, and cognition. In: Farley, F.H., Neperud, R.W. (eds.) The foundations of Aesthetics, Art, & Art Education, pp. 7–42 (1988)
26. Martindale, C.: The pleasures of thought: a theory of cognitive hedonics. J. Mind Behav. **5**, 49–80 (1984)
27. West, A., Moore, K., Martindale, C., Rosen, K.: Prototypicality and preference. Bullet. Br. Psychol. Soc. **36**, A138–A138 (1983)
28. Schubert, E., Hargreaves, D.J., North, A.C.: A dynamically minimalist cognitive explanation of musical preference: is familiarity everything? Front. Psychol. **5**, 38 (2014)
29. Schubert, E.: The fundamental function of music. Musicae Sci. **13**, 63–81 (2009–2010)
30. Davies, S.: Musical Meaning and Expression. Cornell University Press, Ithaca (1994)

31. Hammond, K.J., Seifert, C.M.: A cognitive science approach to case-based planning. In: Chipman, S., Meyrowitz, A.L. (eds.) Foundations of Knowledge Acquisition: Cognitive Models of Complex Learning, vol. 194, pp. 245–267. Springer, Berlin (1993)
32. Tomkins, S.S.: Script theory: differential magnification of affects. In: Howe, H.E., Dienstbier, R.A. (eds.) Nebraska Symposium on Motivation, vol. 26, pp. 201–236. University of Nebraska Press, Lincoln (1979)
33. Schank, R.C., Abelson, R.P.: Scripts, Plans, Goals and Understanding: An Inquiry into Human Knowledge Structures. Lawrence Erlbaum, Hillsdale (1977)
34. Riesbeck, C.K., Schank, R.C.: Inside Case-Based Reasoning. Lawrence Erlbaum Associates, Hillsdale (1989)
35. Kolodner, J.: Case-Based Reasoning. Morgan Kaufmann, San Mateo (1993)
36. Somers, H.: Translation memory systems. In: Somers, H. (ed.) Computers and Translation: A Translator's Guide, pp. 31–48. Benjamins, Amsterdam (2003)
37. Finnäs, L.: How can musical preferences be modified - a research review. Bullet. Counc. Res. Music Educ. **102**, 1–58 (1989)
38. Hargreaves, D.J., Hargreaves, J.J., North, A.C.: Imagination and creativity in music listening. In: Hargreaves, D., Miell, D., MacDonald, R. (eds.) Musical Imaginations: Multidisciplinary perspectives on creativity, performance and perception, pp. 156–172. Oxford University Press, Oxford (2012)
39. Dowling, W.J., Harwood, D.L.: Music Cognition. Academic Press, London (1986)
40. Narmour, E.: The Analysis and Cognition of Basic Melodic Structures: The Implication-Realization Model. University of Chicago Press, Chicago (1990)
41. Bharucha, J.J., Stoeckig, K.: Priming of chords: spreading activation or overlapping frequency spectra? Percept. Psychophys. **41**, 519–524 (1987)
42. Collins, A.M., Loftus, E.F.: Spreading activation theory of semantic processing. Psychol. Rev. **82**, 407–428 (1975)
43. Oja, E.: Simplified neuron model as a principal component analyzer. J. Math. Biol. **15**, 267–273 (1982)
44. Zajonc, R.B.: Attitudinal effects of mere exposure. J. Pers. Soc. Psychol. **9**, 1–27 (1968)
45. Zajonc, R.B.: Mere exposure: a gateway to the subliminal. Curr. Dir. Psychol. Sci. **10**, 224–228 (2001)
46. Stewart, J.: Calculus, Concepts and Contexts. Brooks, Brooks/Cole, Belmont (2009)
47. Smith, E.R., Zarate, M.A.: Exemplar and prototype use in social categorization. Soc. Cogn. **8**, 243–262 (1990)
48. Griffiths, T.L., Canini, K.R., Sanborn, A.N., Navarro, D.J.: Unifying rational models of categorization via the hierarchical Dirichlet process. In: Proceedings of the 29th Annual Conference of the Cognitive Science Society, pp. 323–328 (2007)
49. Pearce, M.T.: The construction and evaluation of statistical models of melodic structure in music perception and composition. Doctoral dissertation, Department of Computing, City University, London, UK (2005)
50. Bunton, S.: Semantically motivated improvements for PPM variants. Comput. J. **40**(2/3), 76–93 (1997)
51. Cleary, J.G., Teahan, W.J.: Unbounded length contexts for PPM. Comput. J. **40**(2/3), 67–75 (1997)
52. Ukkonen, E.: On-line construction of suffix trees. Algorithmica **14**(3), 249–260 (1995)
53. Justus, T.C., Bharucha, J.J.: Modularity in musical processing: the automaticity of harmonic priming. J. Exp. Psychol. Hum. Percept. Perform. **27**, 1000–1011 (2001)
54. Tillmann, B., Bigand, E.: Musical structure processing after repeated listening: schematic expectations resist veridical expectations. Musicae Sci. **14**, 33–47 (2010)