EFFECTS OF CLOSE AND DISTANT REVERSE TONAL PATHWAYS IN MUSICAL STIMULI ON RETROSPECTIVE TIME REPRODUCTIONS

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Abstract

Firmino and Bueno (2008) found that retrospective time reproductions decreased in function of the increasing of interkeys distances in 20s-long musical stimuli. If such tonal pathways included intermediate keys, the temporal reduction impact was smaller. The authors proposed the expected development fraction model (EDF-model) with both an implicit working memory (IWM) component representing a subsequent psychoacoustic process through spatial-temporal key coordinates relative to the immediate stimulus regularities and a semantic memory (SM) representing the high order cognitive structure of tonality internalized through long-term passive exposure. After such induction, a comparison process obtains the perceived IWM-duration being shorter than the expected SM-duration, implying a disproportion. A reproduction process applies such fraction to the IWM-duration, leading to time underestimation. In order to verify the EDF-model's presuppositions regarding reverse pathways, this work found that 20s-long music unfolding distant reverse pathways elicited shorter time estimations than close ones.

Firmino and Bueno (2008) examined the effect of sudden and gradual tonal modulation on retrospective time reproductions through experiment and theoretical model. Tonality is the general term of hierarchical structures for tones called keys which constitutes western traditional music. Modulation is a musical development unfolding change from one key to another. Reproduction task is a time estimation made by a chronometer. Retrospective paradigm implies that the subject is warned about time estimation only after stimulus presentation (Zakay, 1990). Each subject received one of four 20s-long stimuli: nonmodulation (CC), close sudden modulation (CF), distant sudden modulation (CGb), and distant gradual modulation (CEbGb). The authors found that tonal modulations elicited time underestimations in inverse function of interkey distances or pathways, with a major impact of sudden ones.

Firmino and Bueno (2008) also proposed the expected development fraction model (EDF-model) explaining that when modulating music is presented, an expectation of time development is induced in accordance to the traversed interkey pathway. Such expected virtual time is supposed to be projected by a semantic memory (SM) and is longer than the perceived stimulus duration maintained by an implicit working memory (IWM). SM represents the high order cognitive structure of tonality internalized through long-term passive exposure. IWM represents a subsequent psychoacoustic process through spatial-temporal key coordinates relative to the immediate stimulus regularities. If a time estimation is requested, that disproportion or fraction between SM- and IWM-durations is applied to the IWM-duration leading to the time underestimation.

The tonal pitch space model (TPS-model) by Lerdahl (2001) may offer an additional perspective on this issue. The TPS-model represents the key structure in the form of a toroidal four-dimensional space (see also Krumhansl, 1990). Any pathway between two

keys can be computed regarding their positions in a musical context. Thus, the theoretical conjugation of TPS- and EDF-models may predict the specific effect of tonal modulations on time estimation with some more details. When the tonal pathway is also understood regarding its unfolded corresponding time, the concept of velocity appears, that is, for an equal unit of time, long pathways would imply greater velocities than short ones. A modulating music would induce a feeling of shorter time when it modulates to a distant key than when it moves to a close key or remains in the same key. Such statement also applies to reverse modulations that start at an original key, arrive at a destination key, and return to the original key.

This study aimed at empirical bases for the predictions of EDF- and TPS-models in respect of cognitive spatial-temporal dimensions of tonality sense underlying retrospective time reproductions due to 20s-long reverse modulating music.

Method

The participants were 45 college students (men = 22; women = 23), aged between 17 and 30 years, from University of São Paulo at Ribeirão Preto, Brazil. All participants reported having normal hearing; none reported specific training in music.

The stimuli consisted of three music progressions of 29 isochronous chords, following the basic rules of harmony as found in standard texts (Schoenberg, 1922/1974). All chords were major or minor triads with no omission or doubling of any tone. In accordance to prescriptions by Shepard (1964), each tone was a complex sound composed of five partials in perfect octaves (2:1). Thus, each chord formed a sound pulse with 15 different partials. In the nonmodulation condition (CC), the progression remained in C major. In the close key condition (CFC), the progression started at C major, modulated to F major (pitch distance of 5 relative to C major, in Lerdahl's TPS-model), and then came back to C major. In the distant key condition (CGbC), the progression started at C major, modulated to Gb major (pitch distance of 30, in Lerdahl's TPS-model), and then came back to C major. These musical stimuli were 20s long. Each chord was 0.689s long, except the last chord that was 0.708s long. The experiment was carried out in a quiet room with an IBM-PC notebook microcomputer with an extra keyboard, using WaveSurfer software for task monitoring and response and reproduction time storage.

Participants listened to one of the three music progressions with headphones. At the end, they were unexpectedly requested to reproduce the duration of the listened music (retrospective paradigm). Participants subsequently pressed the "initiate" and the "finish" keys of the extra keyboard, marking with beeps the beginning and ending of a silence time interval, which had to correspond to the listened music duration. The different key (tonality subset) pathways defined the between-group variables.

Results and Discussion

Table 1 displays the means and standard deviations of time reproductions for each group of participants relative to modulating music. There was an overall tendency for time overestimation regarding the 20s of the stimuli. Overestimations were the highest for the nonmodulating progression and, to a lesser extent, for the closely related key condition. An ANOVA confirmed a significant effect of modulation on time estimation, $F(2, 42) = 9.85$ $p < 0.05$ ($MSE = 192.32$). Posthoc analysis using the Duncan test indicated that the longest distance modulation elicited the shortest time estimation.

Table 1. Means and standard deviations of retrospective time estimations for three modulating music (20s each).

Stimuli	Mean (s)	Standard Deviation (s)
$CC_{nonmodulation}$	26.28	4.92
$CFC_{close\ reverse\ modulation}$	25.05	4.21
$CGbC_{distant\ reverse\ modulation}$	19.56	4.08

Bigand, Parncutt, and Lerdahl (1996) showed that the feeling of musical tension was correlated with the distance traversed through pitch space, with more tension for progressions such as CGbC than for CFC or CCC. The present data demonstrate that traversing to a distant key (CGbC) results in a shorter estimated time than traversing to a close key or nonmodulation. This finding is consistent with Firmino and Bueno (2008), who showed a pronounced time underestimation for music exhibiting a sudden modulation at the end (CGb), and a less pronounced one when the modulation was achieved gradually (CEbGb). The present study confirms that bias in time estimation is not strictly caused by the occurrence of a specific event that occurs on time - early or late - at the end of a musical sequence (Boltz, 1989). By contrast, the present modulating music exhibited a gradual modulation in the middle section that moved from the main key.

Such effect is difficult to account for in either the storage size or attention models (Hicks, Miller, Gees, & Bierman, 1976; Ornstein, 1969) of time estimation. All modulating music provided an identically low level of stimulus' surface structure (i.e., number of notes, rhythmic structure or even psychoacoustic features). If we suppose that modulation defined one unit of information at some abstract level, these models should anticipate time overestimation for modulating music in comparison to nonmodulating ones.

Modulation involves large-scale structures. To be perceived, information relative to the initial musical key still needs to be present in working memory when the modulation section occurs (Schacter & Tulving, 1994). Thus, models of time estimation should necessarily contain a memory component to account for this effect. An implicit working memory component (IWM) is likely to play a considerable role in the retrospective time reproduction task, once stimulus and response are nonverbal. The present finding also shows that knowledge of western tonal hierarchies influences musical time estimation in western listeners. The term "tonal hierarchy" is used to designate a "nontemporal" schema of pitch regularities, specific to western music, which is stored in long-term memory. It is nontemporal in the sense that it represents more or less permanent knowledge about the musical system, rather than being a response to a specific sequence of events (Lerdahl, 2001). Accordingly, this high order musical knowledge of tonality relationships has some similarities to the concept of human semantic memory (SM), since both are implicitly acquired by passive environmental exposure (Schacter & Tulving, 1994; Tillmann, Bharucha, & Bigand, 2000).

The EDF-model by Firmino and Bueno (2008) involves these two memory components. In this model, knowledge of western musical hierarchies also includes knowledge of durations of "travel" in tonal pitch space. Implicit learning, occurring in everyday life, results in more than the storing of statistical regularities among tones, chords, and keys (Tillmann et al., 2000). This knowledge was formally described by TPS-model having a toroidal structure for tonal pathways which is quite capable to detail modulations in spatial terms. However, western listeners have also stored the average velocity of western music in its travels through pitch space (Firmino and Bueno, 2008). This temporal information associated with tonal pitch space is activated when listening to western music. The expected SM-duration of a piece is compared to the experienced duration and stored in IWM. Such comparison is expressed as a coefficient calculated by dividing the anticipated

time duration mapped in SM by the perceived duration stored in IWM. This temporal coefficient is applied to IWM duration leading to time underestimation.

After participants are instructed to listen to a piece of music, an attentional process occurs relative to the music. The comparison between the temporal contents from both working and semantic memories occurs during the time reproduction task. The listened music (according to IWM) seems shorter than the expected music (according to SM), so that a subsequent estimation of the music duration will analogously become shorter. The larger the traversed tonal pitch space is, the shorter the time estimation will be. There will be greater impact from sudden modulations (i.e., modulating within few chords) than from gradual ones (i.e., with intermediate keys and over several chords; Firmino & Bueno, 2008).

To summarize, when gathered together, the EDF- and TPS-models may explain the shorter duration estimation for the CGbC stimulus than for the CC and CFC stimuli. The key-change velocity concept is associated with time underestimations. Lerdahl's TPS-model offers quantified pitch/chord/key cognitive distances that extend such idea. The EDF-model accounts for forward and reverse modulations concerning timing effects.

Acknowledgements

J. L. O. Bueno received a research fellowship from CNPq and research grants from CNPq and FAPESP. J. L. O. Bueno and E. Bigand received financial support from International Cooperation Program CAPES/Cofecub.
The authors would like to thank João Luís Segala Borin for his technical support.

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