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Harmonic context influences pitch class equivalence judgments through gestalt and congruency effects

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ABSTRACT

The context in which a stimulus is presented shapes the way it is processed. This effect has been studied extensively in the field of visual perception. Our understanding of how context affects the processing of auditory stimuli is, however, rather limited. Western music is primarily built on melodies (succession of pitches) typically accompanied by chords (harmonic context), which provides a natural template for the study of context effects in auditory processing. Here, we investigated whether pitch class equivalence judgments of tones are affected by the harmonic context within which the target tones are embedded. Nineteen musicians and 19 non-musicians completed a change detection task in which they were asked to determine whether two successively presented target tones, heard either in isolation or with a chordal accompaniment (same or different chords), belonged to the same pitch class. Both musicians and non-musicians were most accurate when the chords remained the same, less so in the absence of chordal accompaniment, and least when the chords differed between both target tones. Further analysis investigating possible mechanisms underpinning these effects of harmonic context on task performance revealed that both a change in gestalt (change in either chord or pitch class), as well as incongruency between change in target tone pitch class and change in chords, led to reduced accuracy and longer reaction times. Our results demonstrate that, similarly to visual processing, auditory processing is influenced by gestalt and congruency effects.

1. Introduction

To enable goal-directed behavior and survival in a complex environment, our cognitive system is faced with the challenging task of constructing a valid representation of the world around us based on the available environmental stimuli. This requires the ability to attend to relevant stimuli while ignoring irrelevant ones. When processing and interpreting relevant stimuli, contextual information and the gestalt resulting from its juxtaposition with the relevant stimuli plays a substantial role (e.g., McClelland & Rumelhart, 1981). This implies that the processing of a specific stimulus is constrained, and can be significantly influenced, by the context within which it appears. Much is known about the importance and effect of contextual information in the field of visual processing. This has commonly been demonstrated through examples of visual illusions (Clifford & Rhodes, 2005), in which visually perceived stimuli differ from their objective reality on account of their placement within a particular context (Schwartz, Hsu, & Dayan, 2007), as well as cognitive interference tasks, such as in the Stroop (1935) and Eriksen flanker (Eriksen & Eriksen, 1974) tasks, in which the task-relevant and task-irrelevant stimuli trigger incompatible responses leading to cognitive interference situations. However, our understanding of how context affects auditory processing remains rather limited (Bigand & Tillmann, 2005). Here, we investigate the importance of contextual information for the processing of tones, focusing specifically on the detection of pitch class change.

Tones, the basic building blocks of a melody, can, besides other sound properties such as intensity (amplitude) and timbre, be characterized by pitch (Sundberg, 1991)—a sensation in terms of which the sound may be ordered on a scale from low to high, and which is chiefly a function of its fundamental frequency (ASA, 1960 in Plack, Oxenham, Fay, & Popper, 2005; ANSI, 1994 in Plack et al., 2005; Krumhansl & Shepard, 1979; Randel, 2003, p. 661). It consists of two components: pitch height, which defines a position of a tone on a continuum from low to high, and pitch class, which defines the position of a tone within an octave (Shepard, 1964; Deutsch, 1986). In Western music, pitch class is commonly labeled by a note-name (e.g. pitch class C). Tones that are separated by one or more octaves (a musical interval that corresponds to a doubling of the fundamental frequency) belong to the same pitch class (e.g., pitch class C in any octave). Moreover, such tones exhibit strong perceptual similarity and are perceived to be in some sense equivalent (Demany & Armand, 1984; Deutsch, 1972; Krumhansl, 1979; Krumhansl & Shepard, 1979; Randel, 2003; Shepard, 1964). This

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phenomenon, known as octave equivalence, is present in most musical systems (Nettl, 1956) and was observed both in children and in adults (Baird, 1917; Beate, Stoel-Gammon, & Kim, 2008; Demany & Armand, 1984; Dowling & Hollombe, 1977; Lockhead & Byrd, 1981; Ward & Burns, 1982).

In Western music a leading melody is generally accompanied by other melodies or by chords (simultaneously sounding tones) (Malm, 1996). The context in which the melody is placed significantly shapes the way we perceive the melody itself (Tillmann, Bharucha, & Bigand, 2000). Whereas the effect of melodic context (sequential presentation of tones) has been extensively studied (e.g. Deutsch, 1982; Dowling & Hollombe, 1977; Repp, 2010), not much is known about the manner in which the chordal context (simultaneous presentation of chords together with the target tones) influences the processing of target tones, and specifically the detection of pitch class equivalence. Previous research has suggested that tones belonging to the same pitch class can have different perceptual qualities depending on the context in which they occur (Krumhansl & Shepard, 1979). With the exception of a small subset of studies (e.g. Krumhansl, 1979; for a review see Krumhansl & Cuddy, 2010), the existing research mostly focuses on the effects of context on pitch height similarity judgments, not pitch class per se. Moreover, the effect of embedding tones within a chordal context, as is generally the case in Western music, has not been studied in detail. We addressed this issue by investigating the extent to which the chordal context affects pitch class equivalence judgments of tones being an octave apart, and by evaluating possible underlying cognitive mechanisms.

One possible way of testing whether the chordal context affects pitch class equivalence judgments is to expose participants to the same tone, embed it within two different chords, and examine whether listeners will judge it as the same or different. To illustrate this, let us make an analogy with the well-known Ebbinghaus visual illusion (Roberts, Harris, & Yates, 2005) in which two circles of identical size are placed near each other, one surrounded by large circles, and the other by small circles. As a result, the central circles are judged to be of different size — the circle surrounded by smaller circles appears bigger than the circle surrounded by bigger circles (Fig. 1A).

Analogously, to assess the effect of chordal context on pitch class equivalence judgments, we designed a *pitch class change detection task* in which participants were required to respond to the presence or absence of a change in pitch class between two successively presented target tones that were embedded in a stable or changing chordal context (Fig. 1B). This enabled us to investigate the effect of context on pitch class detection by comparing task performance when tones belonging to the same pitch class were accompanied by the same chords, versus when they were accompanied by different chords. Any change in detection due to change in chords should be reflected in reduced accuracy and/or reaction times.

When interpreting possible changes in task performance due to presence or absence of change in the accompanying chords, a number of cognitive mechanisms may be considered. For the participant to provide a correct response, the stimuli need to be processed through a number of stages (Sternberg, 1969). First, the first target tone needs to be perceived, encoded and maintained in the short-term memory to be retrieved after the second target tone is perceived and encoded as well. A comparison of the pitch class of the two target tones can then be made, the decision mapped to the relevant response and executed. Chordal context can therefore influence participants' task performance by influencing stimulus processing at any of these stages. Here, we tested the influence of three possible contextual effects on reaction times and response accuracy in our pitch class change detection task.

First, tone and chordal context might be perceived as a gestalt. The Gestalt theory implies that the perceptual system processes and represents stimuli as a coherent whole rather than as a set of individual items (Koffka, 1999). Therefore, if both the pitch class of the target tones and the accompanying chords are the same, the gestalt remains the

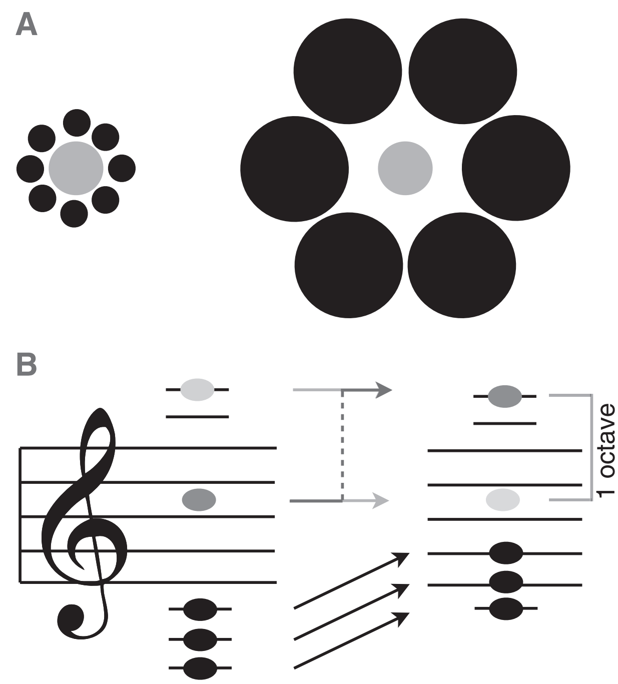

Fig. 1. A) An illustration of the Ebbinghaus illusion. B) The outline of the study design. The gray notes represent the target tones; the black notes represent the chordal context. The arrows mark the transition from the first target tone embedded in the first chordal context to the second target tone embedded in the second context. The figure shows an example in which the pitch class of the target tone remains the same (marked by the gray horizontal arrow) although the second target tone is an octave higher, whereas the chordal context changes (marked by black right upward arrows).

same, making it a salient indicator that the pitch class did not change. However, if either the pitch class or the accompanying chords differ between the two target tones, the gestalt changes as well. In the latter case, we hypothesize that the task is more cognitively demanding, as participants are aware of a change but need to figure out what specifically changed, resulting in longer reaction times and lower accuracy rates. We refer to this possibility as a *gestalt* model of chordal context influence.

Second, as participants might find it difficult to pay attention only to the target stimuli, they might perceive a change (or absence of change) not only in the two target tones but also in the two accompanying chords. In the case in which one component (either tone or chord) changes and the other does not, a response based on the context might compete with the required response to pitch class change judgment, analogous to the effect of distractors in a flanker task (Eriksen & Eriksen, 1974). Such response conflicts would lead both to longer reaction times and to reduced accuracy rates. In contrast, when both target tones and chords change (or when both stay the same), both activate the same response, and such response congruency could facilitate faster and more accurate responses. We refer to this second possibility as a *context-pitch change* congruency (CPC) model.

Third, as studies by Deutsch (Deutsch & Roll, 1974; Deutsch, 1982) have shown, when pitch information needs to be maintained in memory over a short period of time, which is the case in our task due to the sequential presentation of stimuli, pitch information can be encoded in relation to the context. If this is the case, when target tones that differ in pitch class are placed in an equivalent relational context, that is, when the accompanying chords shift in parallel with the target tones so that the overall intervallic (frequency) relationships between tone and chord tones are preserved, participants might be misled by the absence of change in the target tone-chord relation and judge the two target tones to be of the same pitch class (Fig. 2A). Similarly, when two tones of the