HOW DOES THIS SOUND? DIFFERENCES IN PITCH PROCESSING BETWEEN MUSICIANS AND ABSOLUTE PITCH POSSESSORS

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Abstract

According to the ratio effect, when the difference between two magnitudes is large, the comparison between them is faster. This effect complies with Weber's law and was found for many modalities such as numbers, brightness and musical tones. However, the ratio effect is elusive in ordinal scales (i.e., alphabet). Absolute pitch (AP) is a rare ability to identify musical pitches without an external reference tone; in general, most people use the relations between pitches (relative pitch) in order to process musical information. In the current study two groups of musicians (those with AP and controls without AP) were asked to compare pairs of musical tones that varied in their ratio. Results indicated a significant ratio effect only for the controls. Interestingly, AP possessors didn't show such an effect. Accordingly, we suggest that pitch tones can be represented on ordinal or cardinal scales, contingent on AP ability.

Moyer and Landauer (1967) presented participants with a pair of numbers and asked them to indicate the numerically larger number. Participants responded faster when the numerical distance between the numerals was large (e.g., 2 9) rather than small (e.g., 7 9). This effect is known as the distance effect. In addition, for a constant distance, it is easier to discriminate two small numbers (e.g., 2 and 4) than two large numbers (e.g., 6 and 8)—the size effect (Dehaene, 1997). These effects were replicated in many studies and for other magnitudes since they were found. Dehaene (1997) suggested that these two effects are explained by the existence of a mental number line (MNL). The distance and size effects appear because closer numbers on the MNL have overlapping distributions and variability increases with numerical value.

In order to consider simultaneously the sizes of the to-be-compared numbers/quantities and the absolute distance between them (e.g., to consider both size and distance effects), one can calculate the ratio between two stimuli. For example, the distance between 2 and 4, and between 6 and 8 is the same. However, the ratio (smaller divided by larger number) between 2 and 4 is 0.5, while the ratio between 6 and 8 is about 0.75. If ratio matters, it is clear that comparing 6 and 8 is slower than comparing 2 and 4. We will refer to this as the ratio effect. Plotting reaction time (RT) as a function of the ratio between the numbers yields a linear function, complying with Weber's law (for example see Cantlon & Brannon, 2006). According to Weber's law, the stimulus intensity needed to detect a change is a constant proportion of the original intensity of the stimulus rather than a constant amount (Baird & Noma, 1978; Cantlon & Brannon, 2006).

The distance (or the ratio) effect holds for a large variety of cardinal scales (numbers, quantities, physical sizes, etc.). In ordinal scales, such as the alphabet, this effect is more elusive. In 2004, Gevers, Reynvoet and Fias reported a distance effect for days of the week. In contrast, a functional magnetic resonance imaging (fMRI) study compared patterns of brain activation while participants judged whether the order of numbers, sizes of shapes, or letters was correct. Shape sizes and numbers, but not letters, yielded a distance effect, indicating access to a mental continuum. The same study also reported that letters activated different brain regions that were not involved in the distance effect. For example, the anterior cingulate gyrus and the middle frontal gyrus were more active in letter tasks than in number tasks. (Fulbright, Manson, Skudlarski, Lacadie, & Gore, 2003).

A special group of stimuli that is less studied is the auditory pitch tones. Pitch representation is known to be bi-dimensional, having pitch chroma and pitch height. Pitch chroma corresponds to the single elements of the octave (melody), whereas pitch height corresponds to the different octaves or acoustic sources. Shepard (1982) suggested a geometrical organization of musical pitch tones in a complex helix, where pitch chroma is represented by a spiral and pitch height is aligned on a vertical, linear plane. Warren, Uppenkamp, Patterson, & Griffiths (2003) demonstrated distinct brain areas that are responsible of processing these two dimensions.

Cohen Kadosh, Brodsky, Levin, and Henik (2007) examined the distance effect in order to study the mental representation of auditory pitch tones in musically naïve participants. Using a comparison task, the authors found that RT changed linearly with distance, with slower RTs for smaller than larger distances. The distance effect was replicated since most people, both musicians and people without any exceptional musical expertise, process musical information by considering the relation between musical tones and not by recognizing the absolute frequency of each tone. This ability is called relative pitch (RP) ability (Levitin, 1999), and is an important and pertinent ability for musical processing that develops over years of formal musical training. Importantly, there is a small group of musicians that is able to use absolute pitch (AP). AP is a rare ability to identify and produce accurate pitch chroma without any referential tonal context (for a review see Takeuchi & Hulse, 1993). AP is considered to be an inherited ability and its prevalence is estimated to be 1 in 1,500 cases or less in the general population (Baharloo, Service, Risch, Gitschier, & Freimer, 2000; Profita & Bidder, 1988). AP possessors report that identifying pitches is immediate for them and acquired without making any special effort (Takeuchi & Hulse, 1993). AP possessors are faster and more accurate than non AP possessors when asked to identify single tones (Miyazaki, 1988, 1990; Takeuchi & Hulse, 1993).

Is musical pitch representation different for AP possessors and non-AP musicians? Some studies that examined the mechanism that underlies AP (Levitin, 1999; Levitin & Rogers, 2005) suggested that AP possessors are able to match a pitch tone to an internal "pitch template" reference system and to attach a verbal label to it. According to Siegel (1974), AP possessors are able to verbally encode pitch tones. Others demonstrated that AP possessors are not limited to a verbal codification (Zatorre & Beckett, 1989). Ross, Gore and Marks (2005) suggested that in AP possessors, the auditory system is able to translate the pitch chroma into a basic feature. According to the authors, this process reflects a "low-level" pre-attentive mechanism of perception. In addition, Miyazaki (1993, 1995) demonstrated how AP possessors tend to rely on absolute pitch strategies. Furthermore, a recent work by Akiva-Kabiri and Henik (under revision) suggests that AP possessors are able to automatically label musical pitch tones and are unable to supress this process even when irrelevant to the task. This suggests that AP possessors categorize tones and do not use an analog pitch representation in comparative judgment of tones. In contrast, non absolute pitch (nAP) possessors use an analog pitch representation similar to the MNL in the number domain.

The current work aimed to study the representation of pitch tones in AP possessors by using a comparative judgment task of auditory pitches. To this end, we investigated possible differences in the ratio effect, in AP and nAP possessors. We predicted that nAP possessors would show a ratio effect, while AP possessors would show a diminished ratio effect, if any at all.

Method

Participants. Participants included 16 musicians. Seven musicians were AP possessors (2 female and 5 males). AP was assessed by a short test (for further information see http://www.zlab.mcgill.ca). Nine were controls (5 females and 4 males) who were nAP possessors. Musical competence was assessed via a self-reference questionnaire and included information about musical education. For AP possessors mean formal years of musical training was 11.16 (*SD* = 3.5), whereas for nAP possessors it was 8.89 (*SD* = 2.98). Participants were unaware of the experiment's purpose. They all signed an informed consent. The experiment was approved by the local ethics committee.

Procedure. Participants were seated in front of the computers, wearing headphones. The volume was set to the same comfortable level for all participants. Every trial started with a fixation cross for 1000 ms, indicating that a pitch is about to be presented. The tones were presented sequentially one after the other, each for 250 ms. After the second tone, participants were asked to decide, as quickly as possible while avoiding errors, which tone was higher by pressing the P key or the Q key. The next trial started 500 ms after response onset. Response keys were counterbalanced across participants. The stimuli within a block appeared in a random order. The experiment was preceded by an oral and written instructions and a practice block that included 20 random trials. In each block, the same auditory pitch appeared in 2 positions, once as the first tone and once as the second tone. In total, a block contained 96 stimuli: 8 ratios (0.1-0.8) X 2 positions (first vs. second) X 6 pairs of auditory pitches.

Stimuli. Subsets of auditory stimuli were recorded via a piano synthesizer in order to form 9 sound files. Each stimulus was composed of a single pitch tone that was taken from the middle chromatic scale. The chromatic scale divides the octave into 12 tones that are ordered by a distance of one semitone apart from each other. Stimuli duration was 250 ms. Hence, we had 9 semitones (e.g., C4, C#4, D4, D#4, E4, F4, F#4, G4 and G#4) all taken from the same octave, in order to eliminate a possible confound of different octaves.

We attached a numerical value to each tone (1-9) in order to represent its position on the chromatic scale. The auditory stimuli were then paired in order to create couples of tones in eight different pitch ratios (0.1-0.8) (see Table 1). For example, to create the ratio interval of 0.3 we used C#4 (2) and F4 (6) (2/6 = 0.3). For every ratio we used a total of 6 pairs. If there were less than six pairs, we used the same pair a number of times. For example, for ratio 0.1 we used all the pairs twice. Ratio = (small number / large number) to an accuracy of 2 decimal places.

Design. The manipulated variables were group (AP and nAP), and ratio (0.1-0.8). We divided the ratio into two categories: Small ratios (0.1-0.4)—the most dissimilar tones, and large ratios (0.5-0.8)—the most similar tones. Note that the small ratio group contained couples of tones that were a large distance apart from each other, and the large ratio group contained the tones that were a small distances apart from each others. The dependent measures were RT and error rates.

Results

Error rates were low (less than 3%). RT analysis: A two-way analysis of variance (ANOVA) with group (AP and nAP) as a between variable, and ratio (large and small) as a within variable was performed. The analysis revealed a main effect for group—the AP possessors responded faster than the nAP possessors, *F*(1, 14) = 4.65, *p* = .004; and a main effect for ratio—RTs were faster for large ratios (0.1-0.4) than for small ratios (0.5-0.8), *F*(1, 1) = 10.46, *p* = .005. In addition, there was also a marginally significant interaction between group and ratio, *F* (1, 14) = 3.67, *p* = .07. Since we were interested in the specific differences between the groups, we further explored that interaction. Planned comparisons revealed a significant ratio effect for nAP possessors, *F*(1, 14) = 15.16, *p* = .001, and a non-significant effect for the AP group, *F* < 1, *ns*.

Table 1

Pairs of Auditory Stimuli

Category ratio	Ratio	High pitch	Low pitch
0.1	0.11	G#4 (9)	C4 (1)
	0.13	G4 (8)	C4 (1)
	0.14	F#4 (7)	C4 (1)
0.2	0.20	E4 (5)	C4 (1)
	0.22	G#4 (9)	C#4 (2)
	0.25	D#4 (4)	C4 (1)
	0.25	G4 (8)	C#4 (2)
0.3	0.33	D4 (3)	C4 (1)
	0.33	F4 (6)	C#4 (2)
	0.33	G#4 (9)	D4 (3)
0.4	0.40	E4 (5)	C#4 (2)
	0.43	F#4 (7)	D4 (3)
	0.44	G#4 (9)	D#4 (4)
0.5	0.50	C#4 (2)	C4 (1)
	0.50	D#4 (4)	C#4 (2)
	0.50	F4 (6)	D4 (3)
	0.50	G4 (8)	D#4 (4)
0.6	0.60	E4 (5)	D4 (3)
	0.63	G4 (8)	E4 (5)
	0.67	D4 (3)	C#4 (2)
	0.67	F4 (6)	D#4 (4)
	0.67	G#4 (9)	F4 (6)
0.7	0.71	F#4 (7)	E4 (5)
	0.75	D#4 (4)	D4 (3)
	0.75	G4 (8)	F4 (6)
0.8	0.80	E4 (5)	D#4 (4)
	0.83	F4 (6)	E4 (5)
	0.86	F#4 (7)	F4 (6)

Note. The numbers in brackets indicate the corresponding numeral by which we calculated the ratio between the pitches.

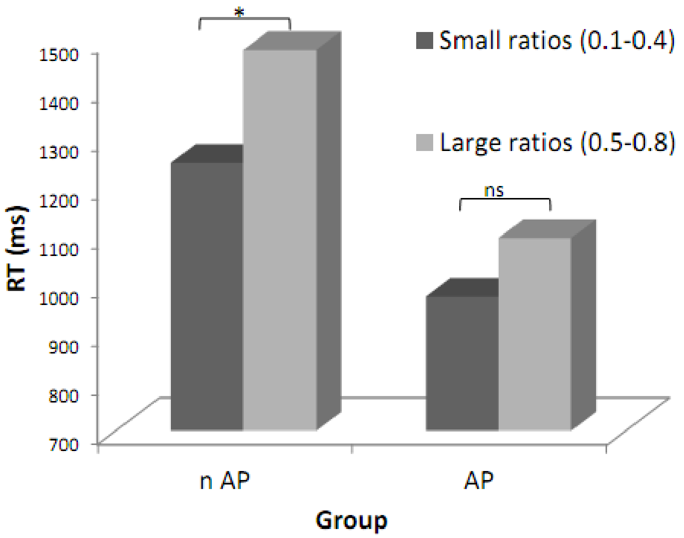

Figure 1— Differences in RT between small and large pitch ratios in AP and nAP groups. ns = non-significant difference, * = significant difference.

Discussion

Musicians with and without AP preformed a comparison of two auditory pitch tones. The nAP group presented a significant ratio effect, as expected according to the literature; namely, RTs were longer for large ratios than for small ratios. Interestingly, AP possessors showed no ratio effect; namely, RTs for small and large ratios were similar. To the best of our knowledge this is the first study that demonstrates the lack of the effect in a particular group of people.

One possible explanation for our results is that the same pitch tones can be represented either on ordinal or cardinal scales, contingent on AP ability; the common way to represent pitch is relative, by comparing it to another pitch. In that case, the representation is on a cardinal scale—not just the order of the pitch tones is relevant, but also the intervals between them. Apparently, such representation is used by nAP possessors. In contrast, AP possessors are able to recognize single pitches and to attach a verbal label to each one of them. In this case, AP possessors are able to compare the two presented tones by their names, and decide which one is higher by retrieving their order in the musical scale; in other words, an ordinal scale representation of the musical scale is enough to perform the task. Previous studies demonstrated that a distance effect might not appear in ordinal scales (i.e., Gevers et al., 2004), possibly the reason for the lack of a ratio effect in our AP group.

Alternatively, it is possible that AP possessors, in addition to their ability to identify pitch tones without any referential tonal context, possess also an enhanced proficiency in recognizing musical intervals. In this case, the absence of a ratio effect might be attributed to the efficiency of these subjects to identify the interval and decide which one of the tones is higher. If such is the case, the results could be observed as a type of “ceiling effect” with both small and large ratios equally easy to compare. To investigate this point, we divided RTs into 4 percentiles and examined the interaction between percentile and the ratio effect for every group. In the AP group, there was no significant ratio effect in any of the percentiles, while in the nAP group, there was a significant ratio effect for all percentiles.

To further study the relation between representation and verbal labels, we are currently conducting a study (Akiva-Kabiri, Leibovich, & Henik, in preparation) where AP possessors compare pitch tones of familiar musical notes (that have verbal representation) and musical pitch tones that do not have verbal representations (i.e., musical scales with intervals that are different from semitones and frequencies that are non pertinent to Western music). By using an unfamiliar set of auditory tones, the participants will be unable to attach verbal labels. They will be forced to compare the intervals between the tones in order to perform the task. If the representation in AP possessors depends on verbal representation, we expect a ratio effect only for musical pitch tones without verbal labels.

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