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Perceiving Rhythmic Repetition and Change Across Development: Effects of Concurrent Pitch

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Abstract

The ability to perceive repetition and change in rhythm is fundamental to music understanding. How is this ability affected by other musical dimensions, such as pitch? We compared the perception of rhythmic repetition and change in rhythm-only stimuli versus rhythm-and-pitch stimuli. A sample of 357 participants, aged from 6 to 22 years, performed Same (repetition) versus Different (change) judgments on rhythmic stimuli with and without concurrent pitch variation. Rhythm-and-pitch stimuli impaired the perception of rhythmic repetition but not the perception of change, and this was independent from participants' age. Our findings are consistent with two concurrent effects of pitch on rhythmic perception: a change-highlighting effect, acting only in rhythmic change, and a working-memory-overload effect that acts in both repetition and change. We discuss the implications regarding composer–listener communication across development.

Keywords

musical understanding, repetition, rhythm, pitch, development

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Introduction

As music listeners, we are able to perceive repetition in a given piece of music (Cuddy, Cohen, & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979; Margulis, 2014; Silva et al., 2014). With more or less conscious awareness, we detect recurrent rhythmic patterns, melodic cells, or harmonic progressions. Perceiving repetition is a key to musical understanding: It aids the segmentation of music into units (Margulis, 2014) based on the principle that something that repeats *is* a unit. Broadly speaking, perceiving repetition is part of our quest for intramusical meaning (Koelsch, 2011)—the type of musical meaning that arises from musical elements referencing to themselves, as opposed to meaning that stems from extra musical references (e.g., flutes emulating bird song). Composers actively make use of repetition, variation (light change), and contrast (heavy change) while attempting to convey intramusical meaning (Kivy, 1993; Ockelford, 2005; Wallin, Merker, & Brown, 2001). Knowing whether and how listeners apprehend these manipulations is fundamental to optimize the aesthetic communication.

Repetition may be perceived in any musical dimension—rhythm (rhythmic patterns), pitch (melodic cells), or harmony (harmonic progressions). Music can be made up of a single dimension (e.g., just rhythm, such as a drum playing solo), but often there is more than one. For instance, a solo flute will contain at least rhythm and melody, with harmony often implied in the latter. In this scenario, one question remains unresolved: When listeners attempt to detect repetition within one target dimension (e.g., rhythm), how is this affected by the presence of concurrent layers of musical information (e.g., pitch intervals)? Shedding light on this fundamental question has several applications, one of these concerning composition and aesthetics: Composers may use this to enhance their manipulations of repetition in music in order to optimize the communication with listeners. In other fields, experimental researchers may use this knowledge to better control for auditory discrimination tasks and know whether concurrent music dimensions affect participants' performance in the change-detection tasks; the same goes for music teachers, when they engage their students in ear training exercises.

In this study, we tested whether a concurrent pitch dimension impairs or benefits listeners' perception of repetition versus change in a (target) rhythm dimension, with *concurrent pitch* referring to the presence (vs. absence) of different pitch values within the rhythmic excerpt, defining a melody. Listeners' perception of repetition versus change was indexed by their accuracy in a Same–Different judgment of two rhythmic phrases presented in succession. They were asked to make judgments on rhythmic pairs under different conditions: With (rhythm-and-pitch stimuli) and without (rhythm-only) a concurrent pitch dimension—a sequence of pitch values that remained unchanged across each pair (Figure 1). The reason why we focused on rhythm as the target dimension relates to its privileged role in carrying repetition. Along with pitch contour—and unlike mode, for instance—rhythm seems to be fundamental in driving the perception of repetition, as it has been empirically shown by a number of studies comparing similarity judgments based on different dimensions (Halpern, 1984; Halpern, Bartlett, & Dowling, 1998; McAdams, Vieillard, Houix, & Reynolds, 2004).

We tested for two different mechanisms of concurrent pitch influences on rhythmic recognition. First, we considered a hypothetical change-highlighting mechanism based on pitch providing redundant evidence of rhythmic change (Deutsch, 1980; Jones, Boltz, & Kidd, 1982; Jones, Summerell, & Marshburn, 1987; Kidd, Boltz, & Jones, 1984; Schmuckler & Boltz, 1994). Given the nature of this mechanism, concurrent pitch should facilitate the detection of rhythmic change but not rhythmic repetition. Here is how the mechanism may operate (Hypothesis 1): Unlike rhythm-only stimuli, rhythm-and-pitch stimuli will drive listeners' attention to pitch, as this is the most salient dimension in Western listening (Prince, 2011; Prince, Thomson, & Schmuckler, 2009). Attending to pitch will make it impossible to ignore rhythm (Jones & Ralston, 1991), and this will be more so if listeners are left without instructions to selectively attend to pitch or rhythm (Prince, 2011; Thompson, 1994). As listeners are driven to rhythm *via pitch,* any rhythmic change will be noticed in both rhythm and pitch (McAuley, 2010). Therefore, listeners will be provided with redundant, extra cues for change detection (rhythm and pitch cues), which may facilitate the perception of rhythmic change. While a single pitch extra cue will be enough to signal rhythmic change, this will not work for rhythmic repetition—where all pitch values will have to be verified. This is why concurrent pitch should facilitate the perception of rhythmic change but not that of rhythmic repetition.

In a different perspective, the fact that rhythm and pitch constitute different streams of information (Monahan & Carterette, 1985; Palmer & Krumhansl, 1987; Peretz & Kolinsky, 1993) raises the possibility that rhythm-and-pitch stimuli challenge working-memory capacity more strongly than rhythm-only stimuli. Silverman's (2010) findings suggested that it might be so: Participants' digit span was larger when digits were coded with concurrent rhythm stimuli then when they were coded with concurrent rhythm-and-pitch ones, suggesting that the latter overload working memory more than rhythm alone. In the context of our study, this would lead to a different type of pitch effects on rhythmic recognition (Hypothesis 2). According to this second mechanism, pitch would impair the perception of both repetition and change, as working-memory capacity would be challenged by concurrent pitch in either case. Thus, according to Hypothesis 1, concurrent pitch would *benefit change* perception, while according to Hypothesis 2, it would *impair both repetition and change* perception.

In our study, we tested for Hypotheses 1 and 2, and we also considered the possibility that both are real (Hypothesis 3), given that they are based on different mechanisms. If it is true that (Hypothesis 1) concurrent pitch is an extra cue for change detection, rhythm-and-pitch stimuli should increase the accuracy for Different but not for Same pairs. In contrast, if (Hypothesis 2) concurrent pitch overloads listeners' working-memory capacity, rhythm-and-pitch stimuli should elicit decreases in accuracy for both Same and Different pairs, compared with rhythm-only stimuli. Finally, if (Hypothesis 3) both influences are real, Different versus Same pairs should dissociate: Change detection (Different pairs) should be simultaneously facilitated (extra cue given, Hypothesis 1) and impaired (overload, Hypothesis 2) by concurrent pitch, these influences should cancel out, and thus rhythm-and-pitch stimuli should be judged as accurately as rhythm-only stimuli; in contrast, repetition detection (Same pairs) should simply be impaired by concurrent pitch (Hypothesis 1), with rhythm-and-pitch stimuli judged less accurately than rhythm-only ones. To test our hypotheses, we thus had to dissociate the perception of rhythmic repetition from the perception of change. Before separating Same from Different pairs in the analysis, we ruled out any effects of concurrent pitch on response bias, as indicated by signal detection measures (see "Methods" and "Results" section).

Our comparison of interest was between *Variable pitch* stimuli (sequence of pitch intervals and melody) and *Fixed pitch* stimuli (flat pitch and monotonic sequence). To keep our hypothesis limited to the effects of a concurrent sequence of pitches, we also investigated the effects of determining pitch per se regardless of its variations in time. Therefore, we compared Fixed pitch (pitch that can be determined) with a third condition that we named *Unpitched* (no pitch to be determined). As the name indicates, it used unpitched timbres, such as tambourine or woodblock.

One last hypothesis (Hypothesis 4) concerned the possible developmental effects on the mechanisms we tested (change highlighting by pitch, working-memory-capacity overload). Given the relevance of our question to music education, we focused on school years, and therefore we collected our data in a sample ranging from 6- to 22-year-olds. Regarding the change-highlighting mechanism, we hypothesized that the potential beneficial effects of judging rhythm using pitch contour segmentation as an extra cue would not change across development, because the perception of pitch contour emerges in the first year of life (Trehub, Bull, & Thorpe, 1984; Trehub & Hannon, 2006), much earlier than the age of our youngest participants. As for the working-memory-capacity overload mechanism, we predicted that it would decrease with age due to the age-related increase in working-memory capacity (Klingberg, Forssberg, & Westerberg, 2002; Thomason et al., 2008). Older participants would be less affected by this mechanism. The verification of Hypotheses 1, 2, and 3 was conditional to Hypothesis 4: In case we saw only a change-highlighting effect (Hypothesis 1), we expected to see no age effects on the enhancing effect of Pitch on Different trials. If there was only a working-memory-capacity overload effect (Hypothesis 2), we expected that the corresponding detrimental effect of Pitch on all trials—Same and Different—would decrease with age. Finally, if we found support for the coexistence of the two mechanisms (Hypothesis 3), we expected that the detrimental effects of Pitch on Same trials decreased with age and that the effects of Pitch on Different trials were detrimental at early ages but became less so throughout development, reaching a zero value (cancelling out of both mechanisms) at some point.

Materials and Methods

Participants

Three hundred and fifty-seven participants (222 females, age range: 6–22 years; 6–12 years, $n = 214$; 13–18 years, $n = 112$; 19–22 years, $n = 31$) participated in this study. Forty-five of these had had musical training in a specialized music school (average 4.5 years of training, range of 1–11 years). No participants reported developmental disabilities, neurological disorders, or any injury or disease affecting audition, cognition, or brain function. Written informed consent was obtained from all participants or from their legal guardians.

Materials

We created 20 pairs of musical sequences (see Appendices A and B), which were presented under three *Pitch* conditions (20×3): *Unpitched*, *Fixed pitch* (constant pitch across the sequence), and *Variable pitch* (changing across the sequence and generating pitch contour). Sequences were composed in collaboration with professional musicians for the purpose of this study. Computer-generated (MIDI) versions of the stimuli were created with Logic Pro X (https://www.apple.com/logic-pro/) and edited with Audacity (http://www.audacityteam.org/). The MIDI (Musical Instrument Digital Interface) values were specified in the software editor, with no human performance involved. Intensity was kept constant. Sequences were delivered in piano or marimba sound for Fixed and Variable pitch sequences and in tambourine or woodblock for Unpitched ones (Table 1). Timbre remained constant across each sequence. Fixed pitch stimuli were

Table 1. Comparison of Same Versus Different Stimuli for Timbre and Mode.

Item property	Same ($n = 8$)	Different ($n = 12$)
Timbre		
Piano/Tambourine	4	6
Marimba/Woodblock	4	6
Mode		
Major	6	9
Minor	2	3

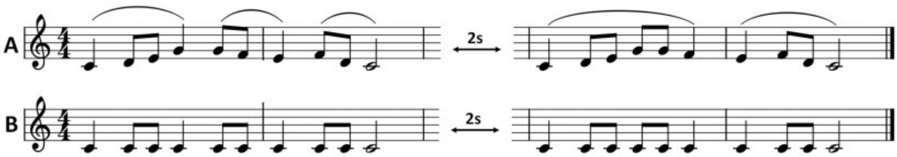

Figure 1. Example of a different pair under variable pitch (a) and fixed pitch (b; Stimulus 14, see Appendix 2).

delivered on the start pitch of the variable pitch sequences (e.g., Pitch C, for the example given in Figure 1).

The 20 pairs of musical sequences consisted of 12 Different pairs and 8 Same pairs (condition Status). We chose not to present an equal amount of Different and Same pairs (e.g., $10 + 10$) so as to counteract participants' expectations. We also did not derive Different from Same, as it is common in this kind of tasks: The 20 pairs were instead created from scratch. We did so because the 20 pairs would be presented 3 times (Unpitched, Fixed pitch, and Variable pitch), and we wanted to evade the excessive repetition that would stem from using 2 (Status levels) $\times$ 3 (Pitch levels) versions of each stimulus. Stimuli were designed such that Different pairs were equivalent to Same, concerning critical memory-capacity-related properties (Schaal, Banissy, & Lange, 2015, see Table 2). Different pairs were created by changing rhythmic fragments no longer than one bar (see Appendix B). With the exception of one stimulus (Stimulus 18), changes were made by reordering the pattern of short and long notes (pattern reversal). These alterations are known to be better recognized than those that keep the pattern of relative durations and modify only the ratio between successive events (Schulkind, 1999).

Procedure

Data collection was carried out in group sessions with a maximum of 20 participants each. Participants sat comfortably in a quiet testing room with a writing answer sheet in front of them. Prior to the experimental task, participants filled in a questionnaire on sociodemographic characteristics.

Each experimental trial consisted of a warning tone, followed by 750 milliseconds of silence and then a pair of rhythmic phrases separated by a 2-second silent interval. Participants were asked to judge whether the two phrases were either the same or different. They had 15 seconds to mark their answer on a paper, after which a new trial would follow. The youngest participants (6- to 10-year olds) were given additional instructions to prevent distraction: The task was presented as a game, and the experimenter made sure that every child had had the time to write down her or his response before proceeding into the next trial.

Table 2. Comparison of Same Versus Different Stimuli for Continuous Variables.

Item property	Same ($n = 8$) Minimum–maximum, mean (*SD*)	Different ($n = 12$) Minimum–maximum, mean (*SD*)	Same versus Different (Z^a, p)
Phrase length (ms)	2,850–6,300, 4,260 (1,020)	3,300–7,300, 5,017 (1,106)	1.095, $p = .181$
Beat length (ms)	429–857, 594 (131)	428–1,000, 719 (177)	0.822, $p = .509$
Minimum note length (ms)	107–600, 326 (128)	200–600, 312 (111)	0.365, $p = .999$
Maximum note length (ms)	321–1,800, 760 (497)	429–2,000, 953 (610)	0.548, $p = .925$
Note length range (ms)	0–1,500[b], 435 (497)	214–1,667, 641 (551)	0.730, $p = .660$
Note length diversity	1–2, 1.75, 1.75 (0.46)	2–3, 2,25 (0.45)	0.548, $p = .925$
Number of notes	8–16, 10.13 (2.75)	7–18, 10.83 (3.30)	0.365, $p = .999$
Note density (notes per second)	1.59–4.05, 2.47 (0.79)	0.96–3.38, 2.26 (0.80)	0.639, $p = .809$
Diversity of metric levels	1–3, 2 (0.53)	2–3, 2.25 (0.85)	0.274, $p = 1.000$

Note. *SD* = standard deviation.

[a]Two-sample Kolmogorov–Smirnov *Z*.

[b]A minimum note length range of 0 means that all lengths in the sequence were equal.

At the end of the session, each child received a gift for participation and good behavior.

Unpitched, Fixed pitch, and Variable pitch stimulus pairs were presented as different blocks. The presentation order of the three conditions was counter-balanced across subjects. Each block comprised 4 practice trials and 20 test trials. A pause of 10 minutes was made after the second block. Each session lasted around 60 minutes in total. Stimuli were delivered through high-quality loudspeakers covering the whole room, thus providing a homogenous listening experience across participants.

Statistical Analysis

Our stimuli varied in *Pitch* (Variable, Fixed, and Unpitched) and *Status* (Same and Different pairs), and our participants had different levels of *Age* and *Musical Experience* (continuous variables). The main focus of our analysis were Pitch effects (Variable vs. Fixed and Fixed vs. Unpitched); the interaction between Pitch and Status (*different Pitch effects* in Same vs. Different); the interaction between Pitch, Status, and Age (different Pitch effects in Same vs. Different *across age*); as well as possible high-order interactions with Musical Experience (different Pitch effects in Same vs. Different *across age or Musical Experience*).

We started with the analysis of *d*-prime and response bias (Stanislaw & Todorov, 1999). *Pitch*, *Age* (continuous variable, in years), and *Musical Experience* (number of years of musical training) entered the analysis as fixed factors and participants as a random factor. The *d*-prime values of the youngest participants (6- to 7-year-olds) were tested against zero with one-sample *t* tests to make sure that same-different discrimination was present at the earliest ages. The analysis of response bias was crucial in that it would grant that the responses to different Pitch categories (e.g., Variable pitch vs. Fixed pitch) were not contaminated by decision-related (postperceptual) influences. After that, we went through our core analysis, which considered the effects of Pitch, Status, Age, and Musical Experience on accuracy.

We used linear mixed models as implemented in the lme4 package (Bates et al., 2015, lmerTest package used for significance values, sjPlot for tables) for R (R Core Team, 2013). Please note that local effect size measures such as partial eta-squared do not apply to linear mixed effects models (Selya, Rose, Dierker, Hedeker, & Mermelstein, 2012), and R^2/Ω_0^2 measures may be used instead as whole-model effect sizes for the purpose of comparison and meta-analysis (Nakagawa & Schielzeth, 2013).

In all analyses, we first compared Variable pitch with Fixed pitch (effects of pitch contour, our main topic), and then Fixed pitch with Unpitched as a control analysis to rule out the possibility that pitch information per se, even though constant, was a relevant dimension.

Results

Figure 2 shows the effects of Age and Pitch on *d*-prime and response bias, and Figure 3 illustrates the effects of Age, Pitch, and Status on accuracy.

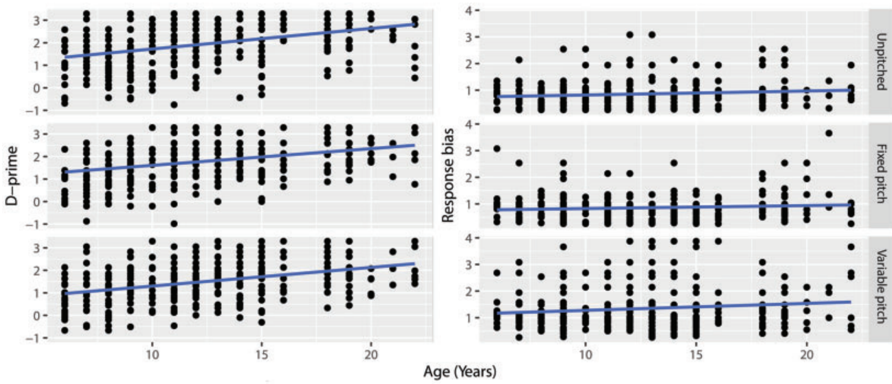

Figure 2. Effects of Age and Pitch on *d*-prime (left) and response bias (right). Regression lines are plotted against individual points/cases.

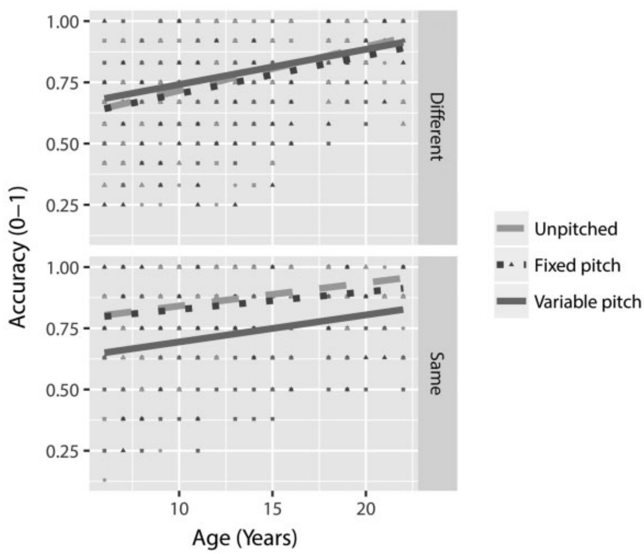

Figure 3. Accuracy as a function of Age and Status × Pitch. Regression lines are plotted against individual points/cases.

Variable Pitch Versus Fixed Pitch

Pitch, Age, and Musical Experience effects on d-prime and response bias (Figure 2; Table 3): The *d*-prime values of the youngest participants were significantly larger than zero, Variable pitch: $M \pm$ standard deviation $(SD) = .73 \pm .76$, $t(17) = 4.05$, $p = .001$; Fixed pitch: $M \pm SD = .98 \pm .79$, $t(17) = 5.31$, $p < .001$. The lme analysis (Table 3) showed main effects of Age (increase) and Pitch (Variable > Fixed) on *d*-prime. There were no significant interactions. Response bias showed no effects or interactions at all, suggesting that postperceptual (decision-related) processes did not differ across Variable pitch and Fixed pitch, and that pitch effects on accuracy (see later) do not reflect different response biases.

Pitch × Status × Age effects on accuracy (Figure 3; Table 4): There was no main effect of Pitch (Variable vs. Fixed) on accuracy, but the significant Pitch × Status interaction indicated that the relation between Pitch conditions changed with Status (Same vs. Different): Post hoc analyses showed that there was no significant difference between Variable and Fixed pitch within Different pairs ($B = .05$, confidence interval (CI) [−0.01, 0.11], $p = .085$), while Variable pitch was at disadvantage within Same pairs ($B = -.16$, CI [−0.23, −0.08], $p < .001$). This shows that the *d*-prime difference between Variable and Fixed

Table 3. Predictors of *d*-Prime and Bias for Variable and Fixed Pitch Conditions.

	d-prime			Bias		
	B	95% CI	*p*	*B*	95% CI	*p*
Fixed parts						
(Intercept)	.84	[0.56, 1.11]	<.001	.73	[0.51, 0.96]	<.001
Pitch	−.31	[−0.62, −0.00]	**.049**	.23	[−0.08, 0.55]	.147
Age	.08	[0.05, 0.10]	**<.001**	.01	[−0.01, 0.03]	.311
Musical Experience	.13	[−0.19, 0.45]	.435	−.04	[−0.30, 0.22]	.744
Pitch × Age	−.00	[−0.03, 0.02]	.735	.02	[−0.00, 0.05]	.073
Pitch × Musical Experience	.25	[−0.11, 0.61]	.170	.09	[−0.28, 0.45]	.638
Age × Musical Experience	−.01	[−0.03, 0.01]	.417	.00	[−0.01, 0.02]	.680
Pitch × Age × Musical Experience	−.01	[−0.03, 0.01]	.491	−.01	[−0.03, 0.01]	.444
Random parts						
σ^2		.380			.401	
$\tau_{00,\ \text{participants}}$		0.247			0.000	
$N_{\text{participants}}$		338			357	
$\text{ICC}_{\text{participants}}$		0.394			0.000	
Observations		676			714	
$R^2/\Omega_0{}^2$		.700/.647			.144/.144	

Note. CI = confidence interval; ICC = Intraclass correlation. Boldface values indicate significant effects.

pitch (see earlier) arose primarily from Same pairs. The modulation of Pitch effects by Status did not depend on age (nonsignificant Pitch × Status × Age interaction, Table 3), years of Musical Experience (Pitch × Status × Musical Experience), or an interaction between the two (Pitch × Status × Age × Musical Experience).

Other effects on accuracy (Figure 3; Table 4): For Variable and Fixed pitch trials, accuracy increased with age (Age effect), and it was higher for Same (Status effect). Performance enhancements across age were stronger for Different than for Same (Status × Age interaction), and this did not depend on pitch (nonsignificant Pitch × Status × Age interaction). Musical Experience had no effects.

Table 4. Predictors of Accuracy for Variable and Fixed Pitch Conditions.

	Accuracy		
	B	95% CI	*p*
Fixed parts			
(Intercept)	.54	[0.49, 0.60]	<.001
Pitch	.05	[−0.01, 0.12]	.105
Status	.21	[0.14, 0.27]	**<.001**
Age	.02	[0.01, 0.02]	**<.001**
Musical Experience	.04	[−0.02, 0.10]	.229
Pitch × Status	−.21	[−0.30, −0.12]	**<.001**
Pitch × Age	−.00	[−0.01, 0.00]	.441
Status × Age	−.01	[−0.01, −0.00]	**.002**
Pitch × Musical Experience	.02	[−0.05, 0.10]	.534
Status × Musical Experience	−.03	[−0.10, 0.05]	.474
Age × Musical Experience	−.00	[−0.01, 0.00]	.249
Pitch × Status × Age	.00	[−0.00, 0.01]	.362
Pitch × Status × Musical Experience	.01	[−0.09, 0.12]	.804
Pitch × Age × Musical Experience	−.00	[−0.01, 0.00]	.720
Status × Age × Musical Experience	.00	[−0.00, 0.01]	.545
Pitch × Status × Age × Musical Experience	.00	[−0.01, 0.01]	.995
Random parts			
σ^2		.017	
$\tau_{00,\ \text{participants}}$		0.006	
$N_{\text{participants}}$		357	
$\text{ICC}_{\text{participants}}$		0.260	
Observations		1,428	
$R^2/\Omega_0{}^2$		.509/.483	

Note. CI = confidence interval; ICC = Intraclass correlation.

Table 5. Predictors of *d*-Prime and Bias for Fixed Pitch and Unpitched Conditions.

	d-prime			Bias		
	B	95% CI	*p*	*B*	95% CI	*p*
Fixed parts						
(Intercept)	.83	[0.54, 1.13]	<.001	.70	[0.54, 0.87]	<.001
Pitch	.00	[−0.31, 0.32]	.979	.03	[−0.19, 0.25]	.791
Age	.08	[0.06, 0.11]	**<.001**	.01	[−0.00, 0.02]	.145
Musical Experience	.40	[0.06, 0.75]	**.022**	.06	[−0.13, 0.25]	.543
Pitch × Age	−.01	[−0.03, 0.02]	.540	−.00	[−0.02, 0.02]	.941
Pitch × Musical Experience	−.27	[−0.64, 0.09]	.141	−.10	[−0.36, 0.16]	.437
Age × Musical Experience	−.02	[−0.04, 0.00]	.083	−.00	[−0.01, 0.01]	.905
Pitch × Age × Musical Experience	.01	[−0.01, 0.03]	.362	.00	[−0.01, 0.02]	.617
Random parts						
σ^2		.396			.202	
$\tau_{00,\ \text{participants}}$		0.308			0.021	
$N_{\text{participants}}$		357			357	
$\text{ICC}_{\text{participants}}$		0.437			0.094	
Observations		714			714	
$R^2/\Omega_0{}^2$		.724/.670			.322/.196	

Note. CI = confidence interval; ICC = Intraclass correlation.

Fixed Pitch Versus Unpitched

Pitch, Age, and Musical Experience effects on d-prime and response bias (Figure 2; Table 5): In the Unpitched condition, the youngest participants (6- to 7-year-olds) showed *d*-prime values larger than zero, Unpitched: $M \pm SD = 1.13 \pm 1.13$, $t(17) = 4.26$, $p = .001$. The *d*-prime increased significantly with Age and with Musical Experience (Table 5), but there were no Pitch effects or any significant interactions. Response bias showed no effects or significant interactions.

Pitch × Status × Age on accuracy (Figure 3; Table 6): There were no main effects of Pitch, consistent with nonsignificant differences between Fixed pitch and Unpitched on *d*-prime. Unlike the comparison between Variable and Fixed pitch, there was no significant Pitch × Status interaction: Fixed pitch and Unpitched were equivalent, for both Different and Same stimuli. Pitch × Status × Age, Pitch × Status × Musical Experience, and Pitch × Status × Age × Musical Experience interactions were all nonsignificant.

Other effects on accuracy (Figure 3; Table 6): Paralleling the results for Variable versus Fixed pitch, there were main effects of Age (increasing accuracy) and Status (Same > Different). There was also a Status × Age interaction

Table 6. Predictors of Accuracy for Fixed Pitch and Unpitched Conditions.

	Accuracy		
	B	95% CI	*p*
Fixed parts			
(Intercept)	.54	[0.49, 0.60]	<.001
Pitch	.00	[−0.06, 0.06]	.972
Status	.20	[0.14, 0.26]	**<.001**
Age	.02	[0.01, 0.02]	**<.001**
Musical Experience	.08	[0.01, 0.14]	**.016**
Pitch × Status	.01	[−0.08, 0.09]	.898
Pitch × Age	−.00	[−0.01, 0.00]	.815
Status × Age	−.01	[−0.01, −0.00]	**.005**
Pitch × Musical Experience	−.04	[−0.11, 0.03]	.295
Status × Musical Experience	−.03	[−0.10, 0.04]	.413
Age × Musical Experience	−.00	[−0.01, 0.00]	.080
Pitch × Status × Age	−.00	[−0.01, 0.01]	.756
Pitch × Status × Musical Experience	.00	[−0.10, 0.10]	.964
Pitch × Age × Musical Experience	.00	[−0.00, 0.01]	.606
Status × Age × Musical Experience	.00	[−0.00, 0.01]	.686
Pitch × Status × Age × Musical Experience	.00	[−0.01, 0.01]	.869
Random parts			
σ^2		.016	
$\tau_{00,\ \text{participants}}$		0.008	
$N_{\text{participants}}$		357	
$\text{ICC}_{\text{participants}}$		0.328	
Observations		1,428	
$R^2/\Omega_0{}^2$		.577/.557	

Note. CI = confidence interval; ICC = Intraclass correlation.

(stronger age-related increase for Different), without third-order interactions with Pitch (stronger age-related increase for Different regardless of Pitch condition).

Discussion

Our first goal was to determine whether and how a concurrent pitch dimension affects listeners' perceptions of repetition versus change in rhythm, and we did this by examining participants' Same–Different judgments of rhythm in rhythm-only versus rhythm-and-pitch stimuli. We tested for two possible mechanisms—beneficial versus impairing effects of concurrent pitch, and we considered three possible outcomes: (a) concurrent pitch could have a beneficial, change-highlighting effect, operating only in Different stimuli; (b) concurrent pitch could have a general impairing effect due to working-memory-capacity overload, and both Same and Different stimuli would be less accurately judged under rhythm-and-pitch; and (c) concurrent pitch could have both effects ($a + b$) simultaneously, resulting in a selective impairment of Same judgments: Under rhythm-and-pitch, judgments of Same stimuli would be less accurate due to the impairing effect (b), while judgments of Different stimuli would remain constant due to the mutually cancelling influences of working-memory-capacity overload and change-highlighting effects.

Consistent with Hypothesis 3, we saw that concurrent pitch impaired participants' judgments of Same but not Different (Pitch $\times$ Status interaction). This pattern emerged when we compared Variable (pitch sequences) with Fixed pitch (flat pitch) but not when we compared Fixed pitch with Unpitched (tambourine or woodblock sounds). This indicates that the effects of concurrent pitch are specifically related to pitch change, and pitch perception per se does not impair the perception of repetition or change. Response bias was not significantly affected by Pitch in any of the two comparisons, so these effects do not seem to be related to decision processes. In addition, they were independent from musical experience, even though the latter enhanced discrimination for Fixed pitch and Unpitched collapsed (and also when the three pitch conditions were collapsed, as we saw in a complementary analysis). Expertise effects on discrimination are well known (e.g., Halpern et al., 1998), and we expected to see them in a more clear-cut way, that is, also for Variable and Fitch pitch collapsed. The fact that they were absent in the latter case seems to indicate that concurrent pitch lowers the influence of musical expertise. One possible reason for these apparently inconsistent effects may relate to the modest musical experience of our participants (see "Method" section), which may not have been sufficient to make the effects emerge as they would in a typical sample of experts.

Our findings are consistent with a beneficial effect of concurrent pitch on change detection, but we remained agnostic about the specific ways in which pitch would highlight rhythmic change. Several mechanisms have been proposed to explain how rhythmic changes alter pitch perception (Dowling, 1973; Jones & Ralston, 1991), making pitch an extra cue. One mechanism may relate to the way rhythmic change may affect chunking and storage of pitch contour subsequences (patterns of pitch drop vs. pitch rise). An example is presented in Figure 1(a): In the first sequence of the pair, pitch contour is naturally segmented into subsequences of pitch rise–drop–drop. In Sequence 2 (Different), the changed rhythm induces different pitch contour subsequences (rise and drop—rise and drop). Perceiving these different pitch subsequences—and possibly the accompanying changes in the implicit harmony—may be an extra cue for change perception. Determining the extent to which this mechanism accounts for the facilitating effects of concurrent pitch on change detection remains a challenge for future research.

The possibility that concurrent pitch impairs the perception of repetition but not the perception of change has several implications. First, it suggests that complexity—as expressed by multiple dimensions—does not necessarily impair recognition, paralleling classic findings such as the object superiority effect, wherein a complex, unified visual object facilitates the perception of one of its parts (Weisstein & Harris, 1974). Second, the fact that pitch contour only affects the perception of repetition means that experimental discrimination tasks using rhythm-and-pitch (see, e.g., Bergeson & Trehub, 2006) are not equivalent to those using rhythm-only stimuli in their ability to capture rhythmic discrimination, and the same may apply to ear training exercises made in school settings: Adding pitch to rhythmic stimuli will not enhance the rhythmic performance; it will preserve change detection, but it will hinder repetition detection. A similar reasoning applies to composers' manipulations of repetition and change, and the way they are successfully captured by music listeners.

Our last hypothesis (Hypothesis 4) related to the developmental trajectory of the effects of concurrent pitch on rhythm perception. The effects we saw (selective impairment of repetition detection) were constant across age. This goes against our predictions, in that the developmental pattern expected for Hypothesis 3 (the one we found support to) would imply increasingly less detrimental (Same) and increasingly enhancing (Different) Pitch effects. One possibility is that the task was not sensitive to the working-memory limitations of young children, and only the developmental course of the change-highlighting effect (predicted as constant) was captured. In any case, the pattern of findings we saw has implications to music education and to design of experimental tasks to be used with school-aged participants (see earlier): It indicates that there is no milestone between 6 and 22 years to be considered, and 6-year-olds should show the same constraints as 22-year-old ones, as far as concurrent pitch effects are concerned.

Adding to our main research goals, we found other age-related effects in our study. First, we saw increased accuracy and discrimination across age, consistent with findings of improved discrimination of perceptual information across childhood (Scott, Pascalis, & Nelson, 2007). Second, we saw an interaction between Status and Age, showing that accurate perceptions of rhythmic change (Different) increased with age more than accurate perceptions of repetition (Same), regardless of concurrent pitch.

Concerning future research, a priority is to validate the mechanisms underlying the beneficial effects of concurrent pitch. We hypothesized that pitch aids in change detection because rhythmic changes become apparent in the segmentation of pitch contour (change-highlighting effect), and this could be tested in several ways. First, the rhythmic and melodic structure of multiple-stream stimuli could be manipulated such that the impact of rhythmic changes on pitch contour varies significantly among them (high-impact vs. low-impact on pitch segmentation). Second, the task could be manipulated such that participants are more or less engaged with pitch contour segmentation, besides rhythmic change detection. This could indicate whether activating pitch contour segmentation is actually responsible for the improved detection of rhythmic change. As a more implicit, alternative task, EEG (electroencephalographic) recordings might help determining whether pitch contour segmentation underlies the perception of rhythmic change by providing markers of segmentation.

Another priority is to validate our inference that there were co-occurring, mutually cancelling pitch effects (change-highlighting and working-memory overload) on Different pairs, as we did not get direct evidence of that. Although we did not consider it as a hypothesis in this study, it is possible that the selective impairment in the recognition of Same pairs was due to a single impairing mechanism that acts only on Same pairs and not to the co-occurrence of two different mechanisms, as we hypothesized. One way of validating our inference of a double mechanism for pitch effects would be dissociating change-highlighting from working-memory overload effects. For instance, a 2×2 design, with impact of rhythmic changes on pitch segmentation (V1: high vs. low impact) and pitch-driven working-memory load (V2: high vs. low amount of pitch changes) as factors, could shed light on this. If it is true that the two mechanisms coexist and act the way we think they do, there should be main effects from both pitch-related factors (V1 and V2) on Different pairs (Variable-Fixed): There should also be an interaction between V1 and V2, with high-impact/high-amount and low-impact/low-amount of changes cancelling out pitch effects (Variable = Fixed), low-impact/high-amount impairing rhythmic recognition in Variable pitch (Variable < Fixed), and high-impact/low-amount enhancing it (Variable > Fixed). For Same pairs, we should see effects of V2 but no effects of V1.

We also made a few methodological choices regarding the stimulus set (different melodies for Same vs. Different, unequal number of Same vs. Different pairs) based on arguments we specified in the "Methods" section (evade excessive repetition, prevent participants from guessing based on a 50/50 ratio). These decisions may not have been optimal, and thus other alternatives could be considered in future studies.

Moreover, it may be important to generalize the concept of interacting multiple dimensions—where changes in one dimension affect the perception of the other dimension—beyond the specific case of pitch and rhythm. For instance, it is possible that a similar mechanism is verified with explicit harmony and rhythm (in our study, harmony was likely implicit in the melody), as rhythmic changes may impact on the segmentation of harmonic sequences.

We looked at our findings from the strict viewpoint of musical understanding, but there are also possible implications in the domain of musical pleasure. Musical understanding—including repetition perception—engages expectations, and expectations play a strong role in musical pleasure (Pearce & Wiggins, 2012; Salimpoor, Zald, Zatorre, Dagher, & McIntosh, 2015; Vuust & Kringelbach, 2010; Zatorre, 2015). It is known that both familiarity (repetition) and novelty (change)—which engage fulfilment and violation of expectations, respectively—are necessary for pleasure (Berlyne, 1970; Zajonc, 1968), including pleasure in listening to music (Heingartner & Hall, 1974; North & Hargreaves, 1995, Sloboda, 1991). In this framework, Huron (2006) claimed that the fulfilment of musical expectations is pleasurable because it means success in mastering the environment, while the violation of expectations leads to a similar result through a different path: As listeners detect that their expectations were wrong, they are allowed to restructure them so that they are adjusted to the real world. By doing so, listeners also end up mastering the environment, feeling empowered, and therefore pleased. So, there seems to be a two-way road to pleasure in listening to music—the expectation-fulfillment way and the expectation-violation way. Although Huron's theory is hard to falsify, it is still an important conceptual tool that relates expectations with pleasure.

How does the perception of repetition versus change intertwine with the expectation game? Listening to music engages at least two types of expectations (Rohrmeier & Koelsch, 2012): One type corresponds to structural-learning-based expectations, which engage knowledge on style-specific musical structures (such as the tonal system or the sonata form) and rely on models stored in the long-term memory. Another type of expectations is based on online learning (Rohrmeier, 2009; Rohrmeier & Koelsch, 2012; Rohrmeier, Rebuschat, & Cross, 2011). Online-learning-based expectations depend on knowledge acquired while listening to a particular music piece. They describe listeners' ability to anticipate what comes next based on what they have just heard and stored in the short term or working memory. While the expectation-for-repetition based on structural learning depends largely on the particular style that is evoked as a model (e.g., an African music or minimalist model would create more expectations for repetition than some types of contemporary music), the expectation-for-repetition based on online learning is, in a sense, the only possible expectation: Listeners cannot anticipate the exact details of something that is unknown to them (change); they can only anticipate what they have just heard, which works as a model. In this sense, perceiving actual repetition fulfills listeners' online-learning expectations, while perceiving change violates these. Of course, online-learning-based expectations do not work alone, and the constant interplay between them and structural-learning-based expectations is determinant. But if we could suspend the interplay and focus only on online-learning-based expectations, we would be left with the idea that the two-way road to pleasure comprises the repetition (fulfillment) way and the change (violation) way. A real-life situation where structural-learning-based expectations are minimized may occur after the initial confrontation of music listeners with an innovative, deeply unfamiliar music style: Listeners first realize that the music does not match the models they heard before in their lives (models are evoked, and structural-learning-based expectations are violated), but then, as music unfolds, the models may became useless for prediction (e.g., listeners will stop expecting for the tonic in dodecaphonic music, soon after starting to listen to it).

From this viewpoint, our findings could help drawing some predictions concerning musical pleasure when listening to a new style. First, the beneficial effect of multiple dimensions in detecting change suggests that concurrent pitch impairs the perception of rhythmic repetition (one of the two ways to reach pleasure) but leaves the perception of rhythmic change (the other way) unaffected. Thus, adding pitch to rhythmic sequences following an unfamiliar model would never increase the overall level of pleasure, but it could preserve the change way to it. Second, the fact that age enhances the perception of change but not of repetition suggests that musical pleasure evoked by change within an unfamiliar musical style is likely to gain importance as one grows older. Given that concurrent pitch preserves the change way to pleasure (see earlier), another emerging hypothesis is that pitch-and-rhythm stimuli within innovative styles may become more pleasant with age, compared with rhythm-only stimuli. These possible implications of in the domain of musical pleasure evoked by unfamiliar styles are mere sketches, requiring a long way of empirical testing. Measuring the perception of repetition versus change under multiple versus single dimensions, along with measures of pleasure, would be a first step.

Finally, our study focused on strict rhythmic repetition as opposed to a form of change that stands closer to the idea of variation (light change) than to the idea of contrast: The type of transformations we applied to our stimuli to make them Different likely kept them recognizable. Although change is change, from a purely logical viewpoint, variation and contrast are used by composers as different kinds of tools. Of course, the point where variation becomes contrast is hard to define as it depends on contextual factors, but it can nevertheless be empirically determined. Therefore, a big question that adds to the agenda of future research is whether our findings replicate for repetition versus contrast.

Appendix A

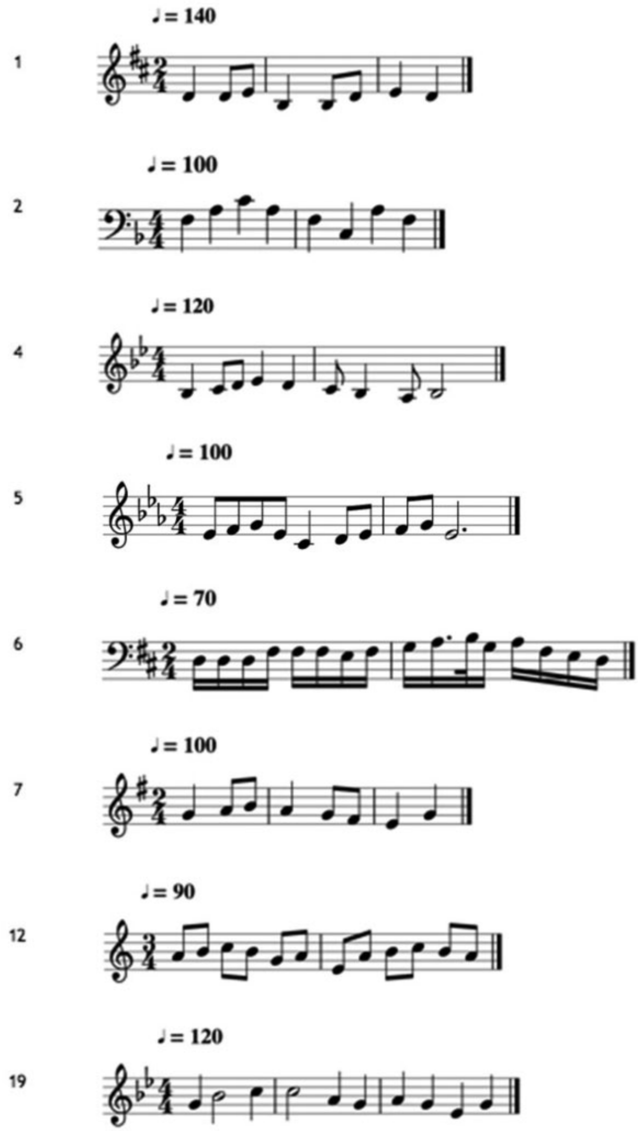

Figure A1. Same stimuli (variable pitch). The stimulus audio files can be downloaded at https://drive.google.com/open?id=1nZrIT3N3l64mmMkoQef5crx_9AFCREwT/

Appendix B

Figure B1. Different stimuli (variable pitch). Stimulus sequences were made different through note inversion (Sequences 3, 10, 13, 15, and 16), pattern inversion (Sequences 8, 9, 11, 14, 17, and 20) and alterations of the rhythm pattern (Sequence 18). The changes made are highlighted.

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