University of Porto

Faculty of Psychology and Educational Sciences

A RITE OF PASSAGE: AGE-RELATED CHANGES IN RHYTHM PERCEPTION

Ricardo Miguel Silva Pereira

October 2016

Dissertation presented for the Integrated Master course in Psychology, Faculty of Psychology and Educational Sciences of the University of Porto, supervised by Professor ***São Luís Castro*** (FPCEUP)

LEGAL NOTICES

Acknowledgements

The current study is the result of a tough but very rewarding experience. Looking back, from the first day I entered this institution, I always knew that my Masters' research would be about music. Now that this aspiration is fulfilled, I must share some words of acknowledgement to all the persons who were involved.

First, to Professor São Luís Castro, my supervisor, for the incessant guidance. It was a tremendous honor to work alongside with such a competent, inspiring and professional person. I am truly grateful for all the effort she put into this work: the hours spent reviewing it, the constant helpful criticism, the enthusiasm demonstrated, the constant readiness to attend my doubts. I cannot express into words how much I have learned and how much her guidance helped me to grow as a researcher.

Thanks to Professor José Nuno Araújo for all the enthusiasm and interest demonstrated. I will always remember his readiness to help me with this work.

I must also thank the Neurocognition and Language Research Group members for being a model of competence, for receiving me so well and for being an example to follow. I must specially thank to Marta for helping me whenever I needed. To Paulo and Helena: sharing the workplace with such competent and joyful people was truly gratifying.

To all my friends and family who always supported me during this whole period. Specially to André, Henrique, Leandro, Luís and Ricardo for all the sleepless nights talking about absolutely nothing. Those were the best of times.

Abstract

Rhythm and pitch are the two main features at the core of any musical structure. These are encoded in the brain from very already on as even neonates show remarkable rhythm and pitch perception abilities. Scientific evidence suggests that these abilities are established at an adult-like level during childhood or early teenage years. With the aim of examining more closely age-related changes in rhythm perception, we conducted a cross-sectional study with 6- to 35-year-old participants who performed a same/different judgement task on three sets of rhythmical note sequences: one with varying pitch contour, another with constant pitch contour and an unpitched tone (e.g., tambourine). These sets were rendered with different timbres (piano, marimba, tambourine and wood block). Participants belonged to five age groups: ages 6 and 7 (N = 44), 8 and 9 (N = 63), 10 to 13 (N = 134), 14 to 16 (N = 68) and 18 to 35 (N = 60). Overall, accuracy was greater for same as compared with different stimuli, and better results were achieved in the unpitched set than in both pitched ones. Age-related changes were observed in the three sets, and in all, rhythm perception reached a plateau by the age of 10.

Keywords: perception; rhythm; pitch contour; age; development

Resumo

Ritmo e altura tonal são duas características fundamentais de qualquer estrutura musical. Admiravelmente, recém-nascidos parecem demonstrar capacidades de perceção destas características, revelando a sua codificação cerebral desde muito cedo. Evidências científicas sugerem que estas capacidades se encontram completamente estabelecidas no fim da infância/início da adolescência. Com o objetivo de examinar mais diferenças relacionadas com a idade na perceção de ritmo, foi realizado um estudo transversal com participantes com idades compreendidas entre os 6 e os 35 anos que realizar uma tarefa de julgamento igual/diferente em três conjuntos de sequências rítmicas: um com variações na altura tonal, um com altura tonal constante e um conjunto com instrumento de altura tonal indefinida (e.g., tamborim). Estes conjuntos foram desenvolvidos em diferentes timbres (piano, marimba, tamborim e bloco sonoro). Os participantes agrupavam-se por grupos de idade: 6 e 7 anos (N = 44), 8 e 9 anos (N = 63), 10 a 13 anos (N = 134), 14 a 16 anos (N = 68) e 18 a 35 anos (N = 60). No geral, a precisão foi maior em julgamentos de sequências iguais, e os resultados foram melhores na condição de altura tonal indefinida do que nas outras. Nas três condições, observaram-se diferenças relacionadas com a idade e, como demonstram os resultados, a perceção rítmica encontra-se estabelecida desde os 10 anos.

Palavras-chave: Perceção; ritmo; altura tonal; idade; desenvolvimento

Introduction

Paraphrasing Paul Hindemith, a well-known German composer, violinist, teacher and conductor, music is nothing but insignificant noise unless it touches a receiving mind. What lies within this musical receiving mind has captured the scientific community's attention from a variety of viewpoints: behavioral, cognitive, developmental, social and neurological ones. Music has been approached as a complex entity composed of multiple components, and each of these is examined in order to understand how human beings process them. A componential view of music can be conceived by taking into consideration basic sound qualities. Thus, we can segregate music into rhythm, dynamics, melody, harmony, tone color or texture. For investigation purposes, pitch and rhythm deserved most attention perhaps because of their impact on everyday perception of musical pieces and of their extensive degree of complexity (Prince, 2014).

Likewise, in this work we focused primarily on pitch and rhythm and on how these are perceived across development. Human beings progressively acquire a large set of cognitive resources during the course of their lives, and music-related abilities are an important among those. Besides maturation, passive exposure to music and the enculturation process may contribute to enhance music perception abilities. In this work we hypothesize that differences in rhythm perception are to be expected across developmental junctures. To begin with, we will review the most relevant investigation on pitch and rhythm development.

1. Development of Pitch Perception

Pitch is a basic property of any given sound and therefore any musical structure. It is a property that allow us to categorize a sound as higher or lower on a frequency scale, and it is measured in Hertz. Pitch, alongside with rhythm, timbre and loudness, is a major perceptual parameter that allows us to differentiate musical notes from noise; it is biologically encoded through a temporal code corresponding to the frequency of the sound, and a spatial code by which different frequencies are embodied across neural tissue in order to produce tonotopic maps (Trainor & Unrau, 2012). Even though human beings are naturally able to distinguish sounds with different frequencies from very early on, pitch discrimination develops across the lifespan and follows the expected development of the auditory cortex. As behavioral paradigms may be problematic to use with infants, event-related brain potentials have been used as an objective and reliable method to investigate the sensitivity to pitch at that tender age. For instance, using the mismatch negativity component – an electrical brain response following an odd stimulus or a rule violation – He and Trainor (2009) established that 4-month-old infants may incorporate harmonic frequencies into a pitch percept, as their brain electrophysiological responses caused a typical mismatch negativity in reaction to the missing fundamental. Maybe more impressively, it is now known that neonates (on day 2 or 3 postpartum) can extract cortical representations of pitch intervals: their brain electrophysiological responses had dissimilar patterns when processing standard intervals and deviant ones (Stefanics, et al., 2009).

It is remarkable how infants in their first year of development, with little or no exposure to music at all, exhibit adult-like processing when dealing with musical stimulus. This pattern is not validated only in event-related brain potentials studies. As infants mature their pitch processing strategies get fine-tuned and manifestations thereof may be captured through behavioral paradigms may. For instance, it is documented that infants between 6 and 8 months of age, similarly to adults, are able to process intervals, distinguishing consonant intervals (sweet, pleasant-sounding intervals, such as the perfect fifth) more efficiently than dissonant intervals (harsh, unpleasant-sounding intervals such as the triton), contradicting the early indications that this aptitude would mature only later in the developmental process (Schellenberg & Trehub, 1996; Trainor, 1997). Another important aspect of pitch, transpositional invariance, also has an early development. It is known that 5- and 6-month-old infants are able to process pitch information and recognize repeated melodies in transposition, that is, melodies transferred up or down in pitch by a constant interval (Plantinga & Trainor, 2005). So, as early as the second half-year of life, humans are able to extract, and be sensitive to, relative pitch representations.

As abovementioned, it is expected that over time children develop finer tuned pitch processing, such as perceiving the directional change of pitch rather than just noticing a difference between frequencies, or discriminating wrong notes within a musical scale: thus, different age groups should show different outcomes in pitch perception tasks. In order to understand when these refined strategies like perceiving directional changes in pitch are established, Stalinski, Schellenberg and Trehub (2008) outlined a simple but effective experiment in which participants from different age groups heard three tones and had to identify whether the midle tone was higher or lower than the other two standard tones. This study concluded that even though they performed more poorly than the other groups, 5 and 6-years-old children were able to detect the direction of pitch changes. It also established that the performance of 8-years-olds' did not differ from that of adults since both groups were able to determine small directional changes of even one-tenth of a semitone. However, in a similar investigation using a different paradigm (an odd-one-out paradigm in which the subjects were presented with three intervals and had to verbally declare whether the first or the third interval was the odd-one, in a pitch-change and a pitch-direction discrimination task) Fancourt, Dick and Stewart (2013) drew different conclusions: although 6 and 7-years-old infants had an adult-like pitch discrimination processing and were capable of detecting directional changes in pitch, this later procedure did not become adult-like until the age of 11 years.

As far as musical scales are concerned, the aptitude to recognize which notes belong to a certain key, or key membership, may require longer time to develop and may require also exposure to the musical scales of one's culture (Trainor & Unrau, 2012). Little is known about how key membership arises in musical settings from cultures other than the Western one, and as such existing evidence relates mainly to the Western culture. In a classic study, Trainor and Trehub (1992) found that adults performed much more efficiently when detecting wrong notes that violated Western musical structure (outside the key) than when the wrong notes remained within the key. By contrast, 8-month-old infants performed equally well in both conditions. Despite these remarkable findings, this study did not establish when key membership arises and also did not take into account the effect of formal musical training biases (some participants had over 10 years of musical training). Nonetheless, in a similar study (Trainor & Trehub, 1994), the same authors asserted that key membership is implicit (does not require musical training) and may develop at about 5 years of age. It was recently suggested that even though prior formal musical training may improve the sense of key membership, this may be mostly a direct consequence of cultural acquaintance and passive exposure to certain keys and timbres (Grannan-Rubenstein, Grannan-Rubenstein, & Thibodeau, 2014; Trainor, Lee, & Bosnyak, 2011).

As remarked by Trehub (2010), in the past 40 years research findings have changed our views regarding the development of pitch perception from a point when children were thought to be unable to do holist auditory processing to nowadays when we recognize their adult-like pitch discrimination abilities. However, while some pitch discrimination features like consonance/dissonance and transposition are known to have an early development, other features such as perceiving the directional change of pitch and key membership have a later development. Harmony syntax processing is another pitch structure that has a rather late development, being probably the last pitch structure to emerge. To the same extent that we need an embedded perception of consonance and dissonance to know which note does or does not belong to a certain key, we also require a perception of these features to know which chord does or does not fit in a certain harmony, as chord progression also follows syntactic rules (Trainor & Unrau, 2012). Trainor and Trehub (1994) recognized the precedence of key membership over harmony processing because as 5-years-old children had better performance with out-of-key changes than with within-harmony or out-of-harmony changes (results that were nevertheless taken to be consisent with the idea of implicit harmonic processing at this young age). Using an easier task, Corrigall and Trainor (2010) found that 4- and 5-year-old children already had some sensitivity to harmony. Nevertheless, it appears that processing harmony syntax is not completely established until late childhood/early teenage years when an abstraction from individual elements such as notes and an attention to the numerous aspects of musical stimuli arise to form an explicitly organized perception of harmony (Costa-Giomi, 2003).

As we have noted, infants and children are inherently musical. Remarkably, as soon as 2 or 3 days postpartum, infants can show interval processing. Pitch lies at the core of a multitude of musical or music-like phenomena, such as tone discrimination, transposition, consonance/dissonance, key membership and harmony processing, that have diverse developmental trajectories. Costa-Giomi (2003) suggested that harmony syntax processing is the last pitch feature to develop, and, consequently, it is the last feature to be completely established as adult-like, possibly in the early teenage years. It is impressing how these pitch processing abilities appear to arise in the absence of formal musical training and may be a result of the simple exposure to music (of course, formal music education in childhood may lead to a more advanced pitch processing system: Trainor & Corrigall, 2010). Investigation on the development of pitch processing has turned its focus mainly to establishing parallels between childrens' and adults' pitch discrimination processes. Nevertheless, it is still rather unclear if, even after all the pitch features are completely established, children, adolescents and adults display different outcomes in pitch discrimination. Given the role of passive exposure to music through life, here we postulate that there may be significant age-related changes in pitch processing from early childhood into adulthood.

2. Development of Rhythmic Abilities

Just like pitch, rhythm is a major feature of any musical structure as it is related to the temporal aspects of sound. Rhythm indicates the temporal organization of sound and it is encoded in two processes, grouping and metrical structure: the first refers to a process that regulates the perception of beginnings and endings of phrases, that is, the duration patterns of notes and silences; the second is specific to all the other rhythmic aspects like beat and meter, that is, the unit of time and its organization on time scales (McAuley, 2010).

Investigation on rhythm perception has also (as in pitch) progressed enormously over the last decades and there is now remarkable evidence of its precociousness and subtlety. Trainor and Adams (2000) established that 8-month-old infants are capable of grouping tone phrases using duration cues. The authors conducted two experiments with 8-month-old infants and adults using an experimental paradigm with isochronous complex tones with the exception that every third complex tone was either longer or louder than the others. Subsequently they inserted silent gaps in three possible locations: between two short/quiet tones, between a short/quiet tone and a long/loud tone and between a long/loud tone and a short/quiet tone. In experiment 1, three conditions were formed depending on whether the starting tone of the three-tone-pattern was the first or the second short tone or the long tone (short-short-long, short-long-short or long-short-short). The task was simply to detect an increase in the silent gap between tones. The authors reported that 8-month-old infants were able to use longer tones to mark phrase endings as their performance was worse in detecting increases in gaps after long tones; this ability was similar to adults'. In another investigation with remarkable conclusions, the authors of a recent event-related brain potentials study presented newborns a drum rhythm pattern composed of snare, hi-hat and bass with four variants following beat omissions in different positions (Winkler, Háden, Ladinig, Sziller, & Honing, 2009). This study revealed that rhythmic violations were captured in the ERP patterns of newborns. This finding challenged the dominant idea that the ability to phrase on the basis of duration cues would arise throughout the first year of life.

Despite this early ability, it is quite likely that infants this young are only able to capture rhythmic patterns in a strong metric framework. Bergeson and Trehub (2006) trained 8 and 9-month-old infants to notice temporal changes in either strongly metric rhythms (all accented tones were associated with a beat) and a weakly metric rhythm (the beats were aligned with accented notes, an unaccented note and empty intervals as well). The authors found that metrical structure has a crucial role when processing rhythmic patterns because the infants could distinguish violation patterns more efficiently in strong meter rhythms than in weak ones. In this study the authors also trained infants to notice pitch changes in the context of duple and triple meter, and they concluded that infants performed more proficiently with melodic sequences in duple meter. This conclusion may suggest a natural predisposition for binary metric framework despite the fact that a fine-grained metric perception may arise by music exposure throughout early childhood (Bergeson & Trehub, 2006).

Recent evidence indicates that rhythm may be organized in distinct skills, such as perception and reproduction (Launay, Grube, & Stewart, 2014; Tierney & Kraus, 2015) contracditing the early indications of a unitary rhythm system (Keele, Pokorny, Corcos, & Ivry, 1985). It has been suggested that rhythm reproduction skills arise throughout preschool years and follow the same structural constraints as rhythm perception: preference for duple meters, for a lesser amount of differences in note durations and for strong metrical structures (Trainor & Corrigall, 2010). A practical way to investigate rhythm reproduction aptitudes on younger children might be examining their movements with music. Eerola, Luck and Toiviainen (2006) outlined an experimental paradigm in order to examine preschoolers' (2 and 4-years-old infants) rhythmic abilities without using tapping skills as a requirement. In this experiment, the authors found that children sometimes exhibited certain movement types alongside with music tempo (hopping, circling or swaying) but none in a statistical significant way. More importantly, they found that children displayed no adjustment to tempo whatsoever. Despite the unforeseen results, this particular study exposed an alternative way to examine younger children's rhythmic reproduction skills and more refined future analysis may provide interesting conclusions regarding this matter. Still, the prevailing idea is that reproduction aptitudes takes years to perfect, and may be a consequence of music exposure.

As was the case with pitch features, rhythm may also be influenced by enculturation process. For instance, in the abovementioned study by Bergeson and Trehub (2006) the authors found that 8- and 9-month-old infants performed more competently with melodic sequences in duple meter (the most regular meter in Western music) comparatively with triple meters, a natural enculturation bias that North American 6- and 7-month-old may not yet have. When presented with either simple or complex meters, these infants were able to detect violations of metrical structure in both meters, in contrast with North American adults, whose performance was superior with simple meters (Hannon & Trehub, 2005). As this study also revealed, the fact that Bulgarian and Macedonian adults also performed as competently in both contexts (complex meters are common in Bulgarian and Macedonian folk music) also uncovers the enculturation process of rhythm that apparently arises in the second half of the first year of life. Additionally, it has been argued that rhythm abilities may also be influenced by rather passive experience such as locomotion and heartbeats (Trainor & Corrigall, 2010)

Despite the scarce developmental evidence regarding children's rhythmic abilities, it is relatively clear that culture-specific rhythm perception becomes completely functional quite early in the development process (Trainor & Corrigall, 2010). It is impressive how these rhythmic aptitudes arise even without formal musical training, and may be a result of rhythmic movements and culture-specific music exposure, despite the fact that formal education in childhood may accelerate this enculturation process and build up an enhanced rhythmic system (Trainor & Corrigall, 2010). Investigation on rhythmic aptitudes has uncovered parallels between children's and adults' in specific rhythmic abilities, but it remains to be seen how general rhythm perception abilities develop across different age groups and different experimental paradigms.

3. The present study

Probably as a result of the current idea that rhythm abilities become established relatively early (Trainor & Corrigall, 2010), age-related changes in rhythm perception are not sufficiently well known. Since rhythm abilities may be organized into multiple skills (Launay, Grube, & Stewart, 2014; Tierney & Kraus, 2015) we hypothesize that significant differences are to be expected between age groups who fully established these skills and age groups who did not. Also, pitch perception undergoes development from early to later childhood and adulthood, and this may impact on how rhythm is perceived in melodic musical excerpts.

The goal of the present study is to examine age-related changes in rhythm perception and if pitch contour may influence the perception of rhythm in same vs. different note sequences. We studied children, teenagers and young adults from the ages of 6 to 35-years-old. They performed a same-different judgement task on the rhythm of note sequences that could also vary in pitch or that maintained the pitch throughout the whole sequence.

Method

1. Participants

Three hundred and sixty-nine participants were recruited to participate in the experiment that took approximately thirty minutes. None of the participants reported hearing difficulties or any other disorder that could have hindered the compliance with the task demands. Informed consent was obtained from participants aged 18 years or more, and from legal guardians of participants under 18 years of age. The declaration of informed consent included a brief explanation of the experiment (see Appendix 1). Prior to the experimental task, participants responded to questions regarding demographics such as education, date of birth, birthweight, weeks of gestation at birth and whether they had had formal musical education (and if yes, for how many years). Participants were divided into five age groups: 6 and 7-years old, 8 and 9-years-old, 10 to 13-years-old, 14 to 16-years-old and 18 to 35-years-old. Sample characterization is displayed below (Table 1).

Table 1. Participants' demographic characteristics.

Age group	**N**	**Age**		**Sex**		**Birth**	**Education**	**Musical education**	
		Mean	**SD**	**Male**	**Female**	**Preterm**	**N**	**N**	**Mean time (years)**
6-7	44	6.57	.50	23	21	5	44 PS	2	1
8-9	63	8.56	.50	27	36	5	63 PS	3	2.67
10-13	134	11.60	.95	52	82	12	21 PS; 112 MS	7	2.23
14-16	68	14.78	.75	29	39	18	44 MS; 24 HS	23	6.18
18-35	60	20.43	3.46	12	48	10	60 C	11	3.73
Total	369	12.50	4.56	143	226	50	-	46	4.42

Note: PS – Primary school; MS – Middle school; HS – High school; C – College

Younger participants came from several schools located in Porto. Older participants were mostly students from Faculty of Psychology and Educational Sciences of University of Porto (except one student that came from School of Engineering – Polytechnic of Porto).

2. Materials

Three sets of 20 pairs of musical stimuli (in addition to the 4 training stimuli for each set) were composed in collaboration with professional musicians: one set with varying pitch contour and two sets with constant pitch contour, as exemplified below (Figure 1). Computer-generated versions of the stimuli were created on Logic Pro X and edited on Audacity with different timbres (piano, marimba, tambourine and wood block).

Figure 1. Example of a pair of stimuli with varying (top) or with constant (bottom) pitch contour. Both delivered in piano at 120 bpm.

The set with varying pitch contour, therefore labelled Changing Pitch condition, was rendered with piano and marimba timbre (10 pairs of each and 2 two additional pairs of each for training). The set with constant pitch contour, therefore labelled Fixed Pitch condition, used the same musical timbres (10 pairs of each timbre and 2 additional pairs of each for training). For these two conditions, the duration of the pairs varied between 8.9 and 17.8 seconds (M = 12.6, SD = 2.1). Finally, the set with constant contour was rendered in unpitched percussion instruments (tambourine and wood block, 10 pairs of each, plus two pairs of each timbre for training) and was therefore labelled Unpitched condition. For this last condition, the duration of each pair varied between 8.6 and 15.3 seconds (M = 11.5, DP = 1.7). All three conditions had 8 equal and 12 different pairs. The training stimuli for each condition had 2 equal and 2 different pairs.

The rhythmic sequences were created in different tempos, time signatures and tonalities, all composed according to the Western musical structure. The characteristics of the stimulus pairs are presented in Table 2.

Table 2. Stimuli characteristics.

Pair	Judgement	Pitched Instrument	Unpitched instrument	Beats per minute	Time signature	Tonality
Ex. 1	D	Piano	Tambourine	100	3/4	D major
Ex. 2	S	Piano	Tambourine	70	6/8	G major
Ex. 3	D	Marimba	Wood block	120	4/4	D minor
Ex. 4	S	Marimba	Wood block	80	3/4	A major
1	S	Piano	Tambourine	140	3/4	D major
2	S	Piano	Tambourine	100	4/4	F major
3	D	Marimba	Wood Block	100	6/8	G major
4	S	Marimba	Wood block	120	6/8	B♭ major
5	S	Marimba	Wood block	100	4/4	E♭ major
6	S	Marimba	Wood block	70	2/4	D major
7	S	Piano	Tambourine	100	2/4	G major
8	D	Piano	Tambourine	120	2/4	G major
9	D	Piano	Tambourine	70	2/4	G major
10	D	Marimba	Wood block	110	6/8	G minor
11	D	Marimba	Wood block	75	2/4	B♭ major
12	S	Marimba	Wood block	90	3/4	A minor
13	D	Piano	Tambourine	140	3/4	E♭ major
14	D	Piano	Tambourine	100	4/4	C major
15	D	Piano	Tambourine	100	3/4	A minor
16	D	Piano	Tambourine	90	6/8	D minor
17	D	Marimba	Wood block	100	4/4	C major
18	D	Marimba	Wood block	70	2/4	D major
19	S	Piano	Tambourine	120	4/4	G minor
20	D	Marimba	Wood block	90	3/4	C major

Note: D – different; S – same.

3. Procedure

Data collection was carried out in small groups, and took place mostly in school rooms.

Before starting the experiment, participants were instructed about the entire procedure. They were told that they would be taking part in an experiment that would explore musical perception in different age groups. The experiment consisted of a simple task where they would hear two sound sequences to which they would have to pay attention and judge whether they were the same or not; they should mark their judgement on a paper that was handout to them. After we were certain that everyone understood this procedure, 4 training stimuli were presented and feedback. Then the remaining stimuli were presented and no feedback was given. Half the participants in each age group started with the Changing Pitch condition, and half with the Fixed Pitch condition. The Unpitched condition was the last one for all participants.

The stimuli were played from a HP computer and amplified with stereo equipment.

4. Statistical Analysis

All statistical analyses were executed using Statistica 10. Analyses of variance (ANOVA) were calculated after confirming sphericity and normality assumptions. Repeated measures general linear models were computed either for an overall analysis and for an analysis by type of judgement. For overall analysis, ANOVAs were computed using participants' total score on each condition as the dependent variable, with Condition as within-subjects factor and Age as between-subjects factor. For the analysis by type of judgment, the ANOVAs were computed with Type of Judgement and Condition as within-subjects factors and Age as between-subjects factor. Tukey HSD tests were used for all post-hoc analyses.

Results

1. Overall Analysis

The ANOVA computed on the percent of correct responses for same and different judgements revealed significant interactions of Condition x Age Group, [$F(8, 724) = 3.73$, $p < .01$, $\eta^2 = .04$]. In the Changing Pitch condition, Tukey HSD post-hoc tests showed that 6- and 7-year-old children' performance [$M = .65$, $SD = .02$] significantly differed from that of 10- to 13-year-old group [$M = .76$, $SD = .01$, $p < .01$], as well as that of 14- to 16-year-old group [$M = .80$, $SD = .01$, $p < .01$], and 18+ group [$M = .81$, $SD = .02$, $p < .01$]. It also revealed that 8- and 9-year-olds' performance [$M = .71$, $SD = .02$] also differed significantly from that of 14- to 16-year-olds [$M = .80$, $SD = .01$, $p < .01$] and from the 18+ group [$M = .81$, $SD = .02$, $p < .01$]. No other significant differences were found between groups in this condition. A graphical representation for rhythm perception in the Changing Pitch condition is shown in Figure 2.

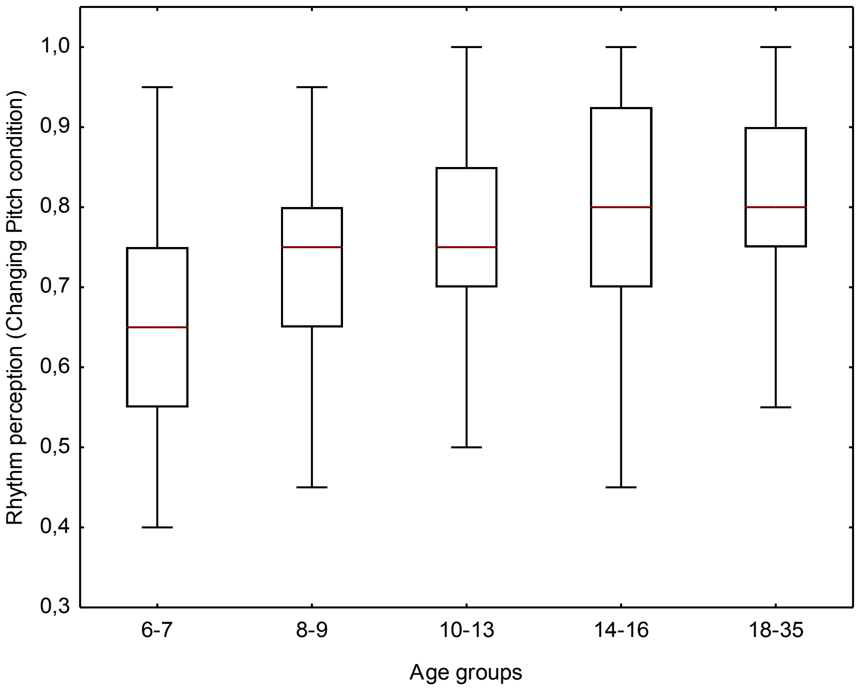

Figure 2. Box plots representing rhythm perception in Changing Pitch condition.

In the Fixed Pitch condition (see Figure 3), post-hoc analyses showed that 6- and 7-year-olds performance [$M = .66$, $SD = .02$] significantly differed from 10-13 year-olds [$M = .81$, $SD = .01$, $p < .001$], from 14-16 year-olds [$M = .78$, $SD = .01$, $p < .001$] and from the 18+ group [$M = .84$, $SD = .02$, $p < .001$]. Additionally, 8-9 year-olds also differed from 10-13 year-olds [$M = .81$, $SD = .01$, $p = .001$] and from the 18+ group [$M = .84$, $SD = .02$, $p = .001$]. No other significant differences were found between groups in this specific condition.

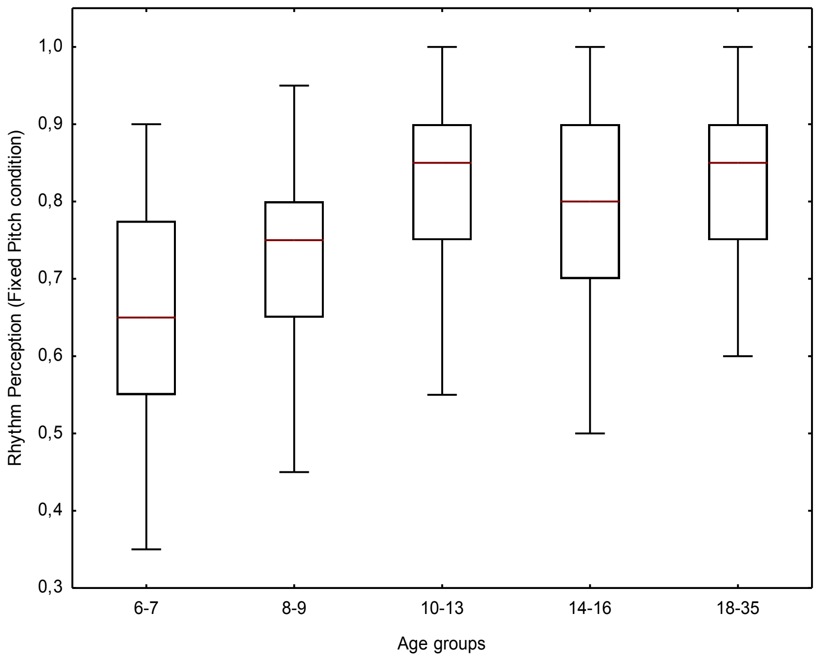

Figure 3. Box plots representing rhythm perception in Fixed Pitch condition.

Finally, in the Unpitched condition (see Figure 4), post-hoc analyses showed that the performance of 6-7 year-olds [$M = .71$, $SD = .02$] significantly differed from that of 10-13 year-olds [$M = .81$, $SD = .01$, $p = .001$], as well as from 14-16 year-olds [$M = .86$, $SD = .02$, $p < .001$] and from the 18+ group [$M = .86$, $SD = .02$, $p < .001$]. The performance of 8-9 year-olds [$M = .71$, $SD = .02$] also differed from that of the older age groups: from 10-13 year-olds [$M = .81$, $SD = .01$, $p < .001$], from 14-16 year-olds [$M = .86$, $SD = .02$, $p < .001$] and from the 18+ group [$M = .86$, $SD = .02$, $p < .001$]. No other significant differences were found between age groups.

As we have seen, the performance of 10 to 13-year-olds group did not differ from the older age groups in the three conditions. Considering that this was the most heterogeneous group, an additional ANOVA was computed considering only for the different groups: 10-year-olds (19 participants), 11-year-olds (40 participants), 12-year-olds (49 participants) and 13-year-olds (26 participants). No significant effect of Condition was found in this analysis [$F(6, 258) = 1.16, p < 1$].

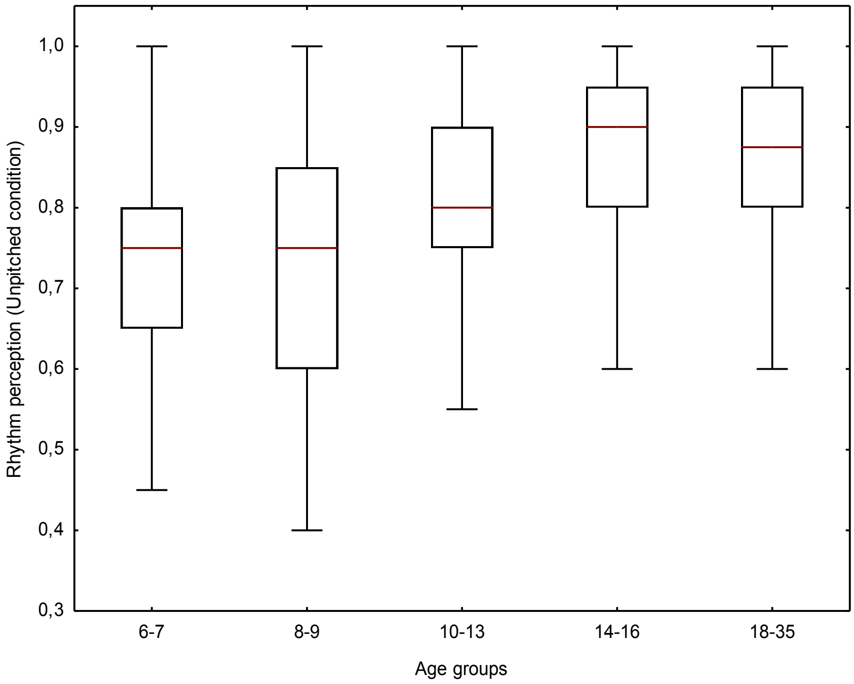

Figure 4. Box plots representing rhythm perception in Unpitched condition.

Post-hoc analyses revealed interesting findings concerning condition differences within a specific group age. For instance, both for 6 and 7-year-olds group and for 8- and 9-year-olds group, the level of performance did not change between conditions. In 10- to 13-year-olds, the results in the Changing Pitch condition [$M = .76$, $SD = .01$] were significantly poorer than results in the Fixed Pitch condition [$M = .81$, $SD = .01$, $p < .001$] and in the Unpitched condition [$M = .81$, $SD = .01$, $p < .01$]. A similar outcome is displayed in the 14- to 16 year-old participants, whose performance in the Unpitched condition [$M = .86$, $SD = .01$] was significantly better than in the Changing Pitch [$M = .80$, $SD = .01$, $p = .01$] and Fixed Pitch conditions [$M = .78$, $SD = .01$, $p < .001$]. Finally, in the 18+ group, no significant differences were found between conditions. Furthermore, in the omnibus analysis we did not find significant Sex [$F(8, 714) = .81, p < 1$], or Preterm condition [$F(8, 562) = .99, p < 1$] effects and so these variables will not be further discussed.

An ANOVA considering only Changing Pitch and Fixed Pitch conditions and including Timbre (piano vs. marimba) was also computed on the overall percent correct responses. We found significant interactions for Age Group x Timbre [$F(4, 364) = 4.01$, $p < .01$, $\eta^2 = .03$]. In the Changing Pitch condition, Tukey HSD post-hoc test showed that 6- and 7-year-olds' performance in piano stimuli [$M = .61$, $SD = .02$] significantly differed from that of 14-16 year-olds [$M = .72$, $SD = .02$, $p < .05$]. Close to significant differences were also found between the 8-9 age group [$M = .62$, $SD = .02$] and 14-16 group [$M = .72$, $SD = .02$, $p = .06$]. Results in the Changing Pitch condition with marimba stimuli also displayed a similar pattern: significantly inferior results from 6-7 age group [$M = .69$, $SD = .02$] comparatively with 14-16 group [$M = .87$, $SD = .02$, $p < .001$] and 18+ group [$M = .90$, $SD = .02$, $p < .001$]; and close to significant differences between 8-9 age group [$M = .77$, $SD = .02$] and 14-16 group [$M = .87$, $SD = .02$, $p = .10$, ns.]. A graphical representation for rhythm perception in both timbres of Changing Pitch condition is represented in Figure 5.

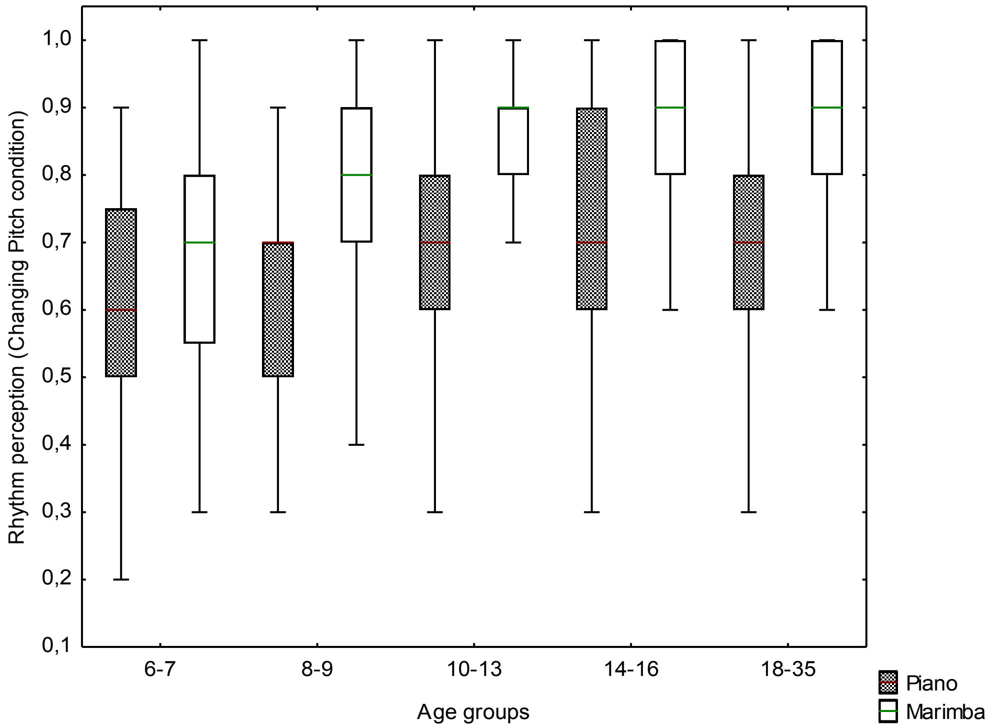

Figure 4. Box plots representing rhythm perception in both timbres of Changing Pitch condition.

In the Fixed Pitch condition with piano stimuli, post-hoc analysis showed a similar pattern: significant differences between the 6-7 age group [M = .65, SD = .02] and the 18+ age group [M = .82, SD = .02, p < .001] and near to significant differences between the 8-9 age group [M = .72, SD = .02] and the 18+ age group [M = .82, SD = .02, p < .10]. However, analysis within the same condition with marimba stimuli revealed that the performance of the 8-9 age group [M = .73, SD = .02] differed from that of the other age groups: 10-13 [M = .84, SD = .02, p < .001], 14-16 [M = .85, SD = .02, p = .02] and 18+ [M = .86, SD = .02, p < .001]. A graphical representation for rhythm perception in both timbres of Fixed Pitch condition is represented in Figure 6.

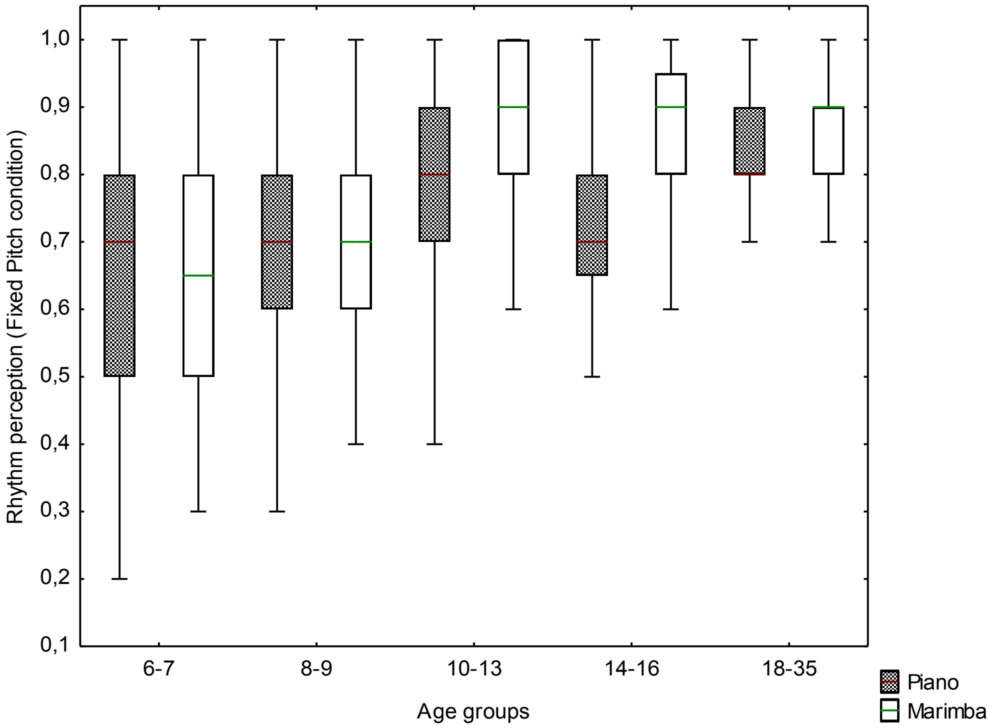

Figure 5. Box plots representing rhythm perception in both timbres of Fixed Pitch condition.

Finally, a separate ANOVA was computed in Unpitched condition. We found significant interactions for Age Group x Unpitched Timbre [$F(4, 362) = 4.61$, $p < .01$, $\eta^2 = .05$]. Tukey HSD post-hoc analysis showed that the performance with wood block stimuli by 6- and 7-year-olds [M = .70, SD = .03] and by 8- and 9-year-olds [M = .70, SD = .02] significantly differed from all the older groups: 10-13 [M = .84, SD = .01, p < .001], 14-16 [M = .87, SD = .02, p < .001] and 18+ [M = .89, SD = .02, p < .001]. However, in addition to the pattern abovementioned, analyses on the tambourine stimuli revealed that the 10-13 age group [*M* = .77, *SD* = .01] significantly differed from the that of the 14-16 group [*M* = .85, *SD* = .01, *p* = .01]. A graphical representation for rhythm perception in both timbres of Unpitched condition is represented in Figure 7.

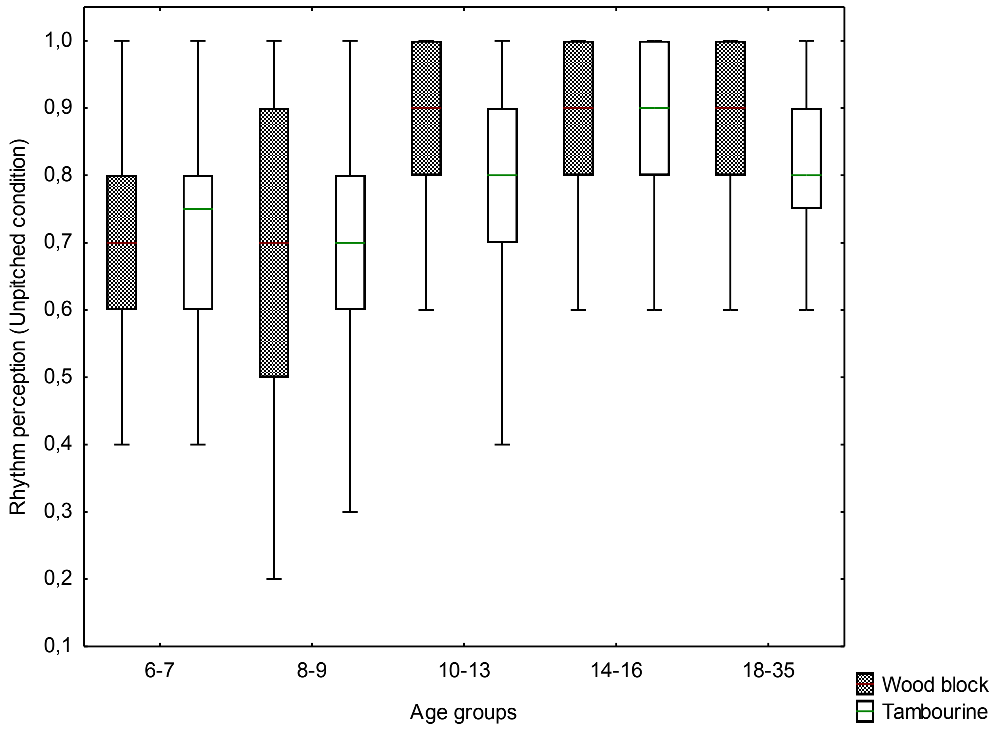

Figure 6. Box plots representing rhythm perception in both timbres of Unpitched condition.

2. Analysis by Type of Judgement

Taking into account type of judgement, the repeated measures ANOVA showed a significant triple interaction of Condition x Type of Judgement x Age Group, [$F(8, 724) = 2.20$, $p < .05$, $\eta^2 = .02$].

In the Changing Pitch condition (see Figure 8), Tukey HSD post-hoc tests showed that 6- and 7-year-olds [*M* = .70, *SD* = .02] perceived similarity as well as older age groups, with significant differences compared to the 18+ group [*M* = .83, *SD* = .02, *p* = .05]. When perceiving differences, however, 6- and 7-year-olds' performance [*M* = .61, *SD* = .02] was significantly inferior to that of the 10-13 year-old group [*M* = .73, *SD* = .01, *p* = .02], 14-16 group [M = .79, SD = .02, p = < .001] and the 18+ group [M = .80, SD = .02, p < .001]. No significant differences were found between the 10-13 year-old group and older age groups.

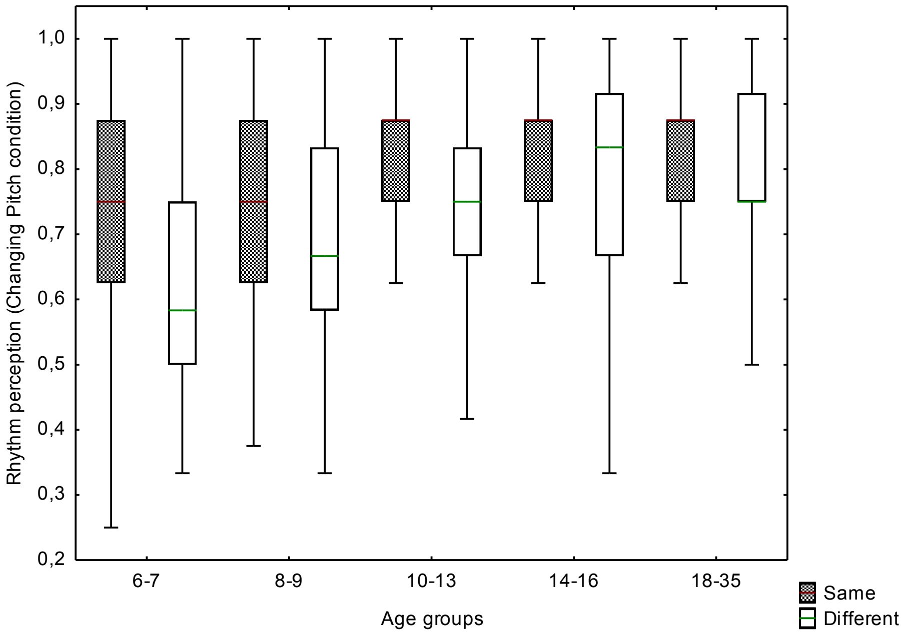

Figure 7. Box plots representing rhythm perception in both types of judgement in Changing Pitch condition.

In the Fixed Pitch condition (see Figure 9), no significant differences were found between groups regarding same judgements. However, on different judgements, 6- and 7-year-olds [M = .58, SD = .02] performed significantly worse than the 10-13 [M = .79, SD = .01, p = < .001], the 14-16 [M = .78, SD = .02, p < .001] and 18+ groups [M = .85, SD = .02, p < .001]. Performance of the 8 and 9-year-olds [M = .70, SD = .02] only differed from the 18+ group [M = .85, SD = .02, p < .001].

In the Unpitched condition (see Figure 10), no significant differences were found between groups regarding similarities. However, regarding different judgements, post-hoc analyses revealed that 8- and 9-year-olds [M = .66, SD = .02] performed less well all the older groups: 10-13 [M = .79, SD = .01, p < .001], 14-16 [M = .86, SD = .02, p < .001] and 18+ [M = .87, SD = .02, p < .001].

Within the same age group, no significant differences were found between conditions for both same and different judgements.

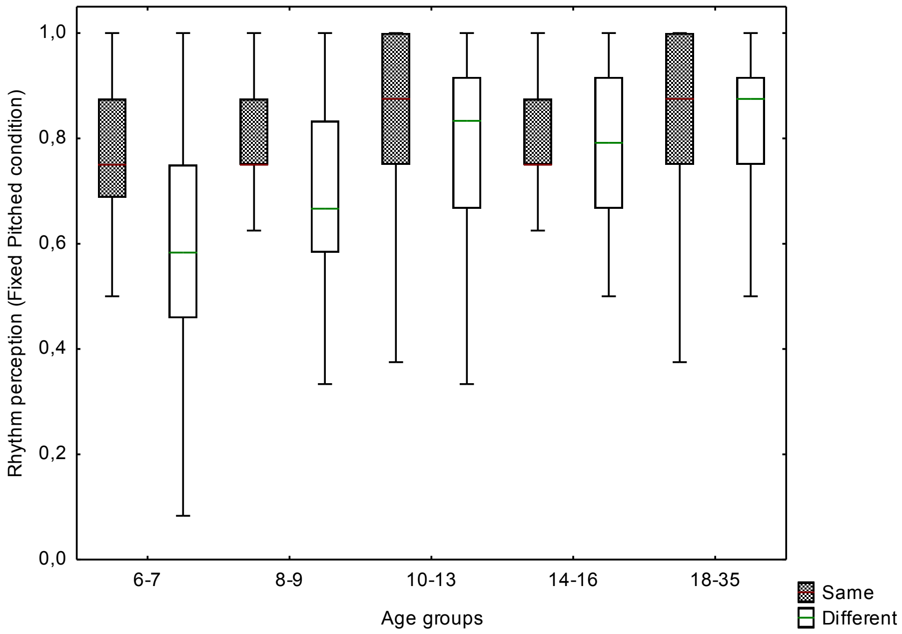

Figure 8. Box plots representing rhythm perception in both types of judgement for Fixed Pitch condition

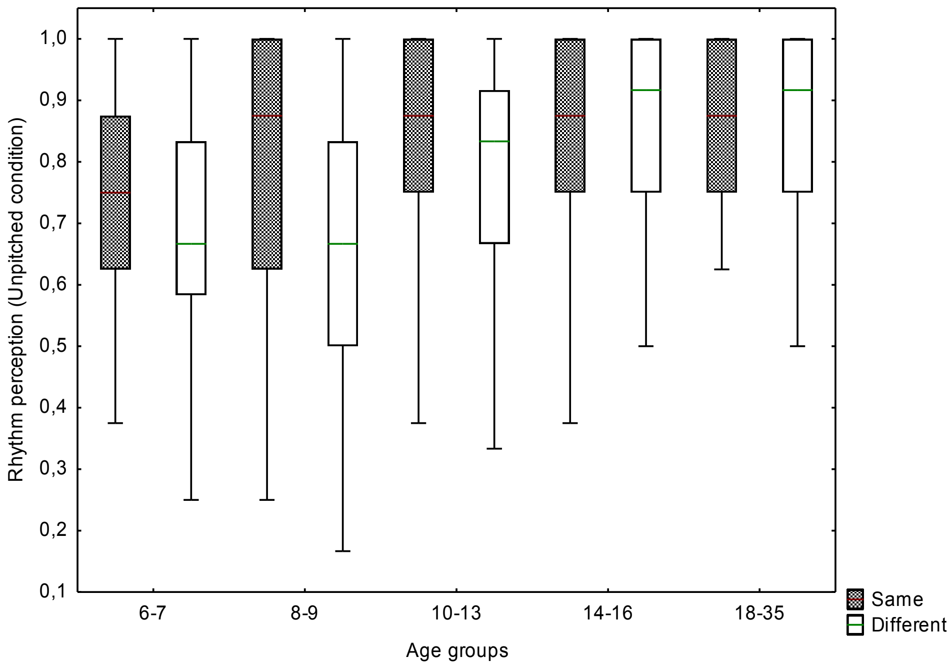

Figure 9. Box plots representing rhythm perception in both types of judgement for Unpitched condition

Further post-hoc tests revealed that in the Changing Pitch condition, the performance of the 14-16 and the 18+ age groups did not differ for both types of judgement. However, this might not be the case for younger age groups. Close to significant differences were found between 6- and 7-year-olds in same [M = .70, SD = .02] and different stimuli [M = .61, SD = .02, p = .09]. We also found significant differences between 8 and 9-years-old age group' performance in same [M = .78, SD = .02] and different stimuli [M = .66, SD = .02, p < .001]. Finally, a similar pattern was found in the 10-13 age group for both same [M = .80, SD = .01] and different stimuli [M = .73, SD = .01, p < .001].

In the Fixed Pitch condition, a similar pattern was found. The two older age groups did not differ regarding both types of judgement. However, significant differences were found between the 6-7 year-old group in same [M = .80, SD = .01] and different stimuli [M = .73, SD = .01, p < .001]. Close to significant differences were found between the 8-9 age group in same [M = .77, SD = .02] and different stimuli [M = .70, SD = .02, p = .10]. Additionally, significant differences were found in the 10 to 13-years-old group between same [M = .85, SD = .01] and different stimuli [M = .79, SD = .01, p = .02].

Finally, in the Unpitched condition, only the 8- and 9-year-olds group differed in same [M = .78, SD = .02] and different stimuli [M = .66, SD = .02, p < .001]. For all the other groups, no significant differences were found.

Discussion and Conclusion

The main goal of the present study was to examine age-related changes in rhythm perception. Considering that we have found significant interactions between conditions and age groups, we will review our findings by taking into account each condition separately.

In the Changing Pitch condition, we have found that both younger groups' performance differed from both older groups. Additionally, we did not find any significant differences between the older groups (from 10 to 13-years-old group to 18+ group). This task involved processing of both rhythm and pitch contour of the note sequences. As both pitch and rhythm are perceived by combining multiple cues, and harmony processing appears to be fully developed only in late childhood (Costa-Giomi, 2003), our results accord well with existing evidence.

In the Fixed Pitch condition, it seems indeed that rhythm abilities continue to improve throughout childhood years (Trainor & Corrigall, 2010) as we found significant differences between the two younger groups and the 10- to 13-year-old group. Furthermore, a similar pattern as the abovementioned was found: younger groups performed significantly poorer than older groups and no significant differences were found between the three older groups. Accordingly, rhythm perceptual abilities seem to reach a plateau by the of 10.

In the Unpitched condition a similar pattern was found: the two younger groups' performance was significantly lower than that of the older groups. Under reduced task demands (no pitch), rhythm discrimination abilities seem to be completely established at an adult-like level by late childhood/early teenage years.

The fact that we did not find a significant effect of condition in the 10- to 13-year-old group indicates that, as early as 10 years of age, children are already equipped with an adult-like rhythm processing system. Costa-Giomi (2003) suggested that younger children might have attentional limits that would not allow them to focus on stimulus relevant features when processing harmony. We suggest that this lack of resources may be seen in rhythm perception as well, and its impact is stronger in younger than older children because younger children have been less exposed to music than older children. Significant differences were found between conditions for older children and adolescents.

As these age groups are able to focus on multiple aspects of musical stimulus (Costa-Giomi, 2003) their performance was probably grounded on this more developed general ability. Unsurprisingly, their performance in the Unpitched condition (which required paying attention to less musical features) was significantly better than in the Changing Pitch and Fixed Pitch conditions.

Processing music is influenced by enculturation and passive exposure to certain keys and timbres (Grannan-Rubenstein, Grannan-Rubenstein, & Thibodeau, 2014; Trainor, Lee, & Bosnyak, 2011). Taking this into account, we looked at the potential impact of instrument type, and we have found significant differences in performance with piano and marimba between younger and older groups. This might be explained by that passive exposure. In the Unpitched condition, a similar pattern was observed in the wood block and tambourine stimuli.

As we reviewed empirical evidence regarding the development of pitch and rhythm perception, we noticed that most studies focus on perceiving differences between musical stimuli. The dominant experimental paradigm relies on urging participants to notice differences. So we were interested in examining specifically the pattern of different vs. same responses. We confirmed that the results from the younger groups significantly differed form older groups when distinguishing between two different stimuli in every condition. Nevertheless, this might not be the same for recognizing similarities: no matter the condition in study, children could identify identical stimuli as competently as older participants did. Of course processing stimuli as identical also requires pitch and rhythm abilities, and we might speculate that at this more holistic level (perceiving similarity) children are already equipped with some overall musical aptitudes in an adult-like way. We acknowledge however that a signal detection theory analysis of the data is an important next step in order to better understand the interplay between same/different responses.

In sum, we showed that childhood stand as a critical period for the development rhythm perception abilities. Late childhood/early teenage years appear to be the period where these abilities are developed at an adult-like level, at least under the task demands studied here. This developmental pattern is probably the result of a combination of multiple cognitive abilities, some general such as attention and some specific such as those related to rhythm and pitch processing, that are driven at least in part by enculturation and music exposure (formal education might accelerate this process).

As limitations of the present study, we point the following: general intelligence was not measured; some participants had formal musical education; data collection was carried out in small groups and thus we also cannot rule out that some sort of social phenomenon might have occurred. Finally, for future research we suggest to include stimuli with more dissimilar characteristics either in key signatures, tempo or timbre.

References

Bergeson, T. R., & Trehub, S. E. (2006). Infants' perception of rhythmic patterns. *Music Perception: An Interdisciplinary Journal, 23*(4), 345-360. doi:10.1525/mp.2006.23.4.345

Corrigall, K. A., & Trainor, L. J. (2010). Musical enculturation in preschool children: acquisition of key and harmonic knowledge. *Music Perception: An Interdisciplinary Journal, 28*(2), 195-200. doi:10.1525/mp.2010.28.2.195

Costa-Giomi, E. (2003). Young children's harmonic perception. *Annals of the New York Academy, 999*, 477-484. doi:10.1196/annals.1284.058

Eerola, T., Luck, G., & Toiviainen, P. (2006). An investigation of pre-schoolers' corporeal synchronization with music. *9th International Conference on Music Perception and Cognition.* Bologna, Italy.

Fancourt, A., Dick, F., & Stewart, L. (2013). Pitch-change detection and pitch-direction discrimination in children. *Psychomusicology: Music, Mind, and Brain, 23*(2), 73-81. doi:10.1037/a0033301

Grannan-Rubenstein, G. D., Grannan-Rubenstein, W. L., & Thibodeau, P. H. (2014). Enculturation effects of musical training on pitch discrimination. *Annual Conference of the Cognitive Science Society*, (pp. 2985-2989). Quebec.

Hannon, E. E., & Trehub, S. E. (2005). Metrical categories in infancy and adulthood. *Psychological Science, 16*(1), 48-55. doi:10.1111/j.0956-7976.2005.00779.x

He, C., & Trainor, L. J. (2009). Finding the pitch of the missing fundamental in infants. *The Journal of Neuroscience, 29*(24), 7718–8822. doi:10.1523/JNEUROSCI.0157-09.2009

Keele, S. W., Pokorny, R. A., Corcos, D. M., & Ivry, R. (1985). Do perception and motor production share common timing mechanisms: a correlational analysis. *Acta Psychologica, 60*, 173-191.

Launay, J., Grube, M., & Stewart, L. (2014). Dysrhythmia: a specific congenital rhythm perception deficit. *Frontiers in Psychology, 5*(18). doi:10.3389/fpsyg.2014.00018

McAuley, J. D. (2010). Tempo and rhythm. In M. R. Jones, R. R. Fay, & A. N. Popper, *Music Perception* (Vol. 36, pp. 165-199). New York: Springer. doi:10.1007/978-1-4419-6114-3

Plantinga, J., & Trainor, L. J. (2005). Memory for melody: infants use a relative pitch code. *Cognition, 98*, 1-11. doi:10.1016/j.cognition.2004.09.008

Prince, J. B. (2014). Contributions of pitch contour, tonality, rhythm, and meter to melodic similarity. *Journal of Experimental Psychology: Human Perception and Performance, 40*(6), 2319-2337. doi:10.1037/a0038010

Schellenberg, E. G., & Trehub, S. (1996). Natural musical intervals: evidence from infant listeners. *Psychological Science, 7*(5), 272-277. doi:10.1111/j.1467-9280.1996.tb00373.x

Stalinski, S. M., Schellenberg, E. G., & Trehub, S. E. (2008). Developmental changes in the perception of pitch contour: distinguishing up from down. *The Journal of the Acoustical Society of America, 124*(3), 1759–1763. doi:10.1121/1.2956470

Stefanics, G., Háden, G. P., Sziller, I., Balázs, L., Beke, E., & Winkler, I. (2009). Newborn infants process pitch intervals. *Clinical Neurophysiology, 120*, 304-308. doi:10.1016/j.clinph.2008.11.020

Tierney, A., & Kraus, N. (2015). Evidence for multiple rhythmic skills. *PLoS ONE, 10*(9). doi:10.1371/journal.pone.0136645

Trainor, L. (1997). Effect of frequency ratio on infants' and adults' discrimination of simultaneous intervals. *Journal of Experimental Psychology: Human Perception & Performance, 23*(5), 1427-1438. doi:10.1037//0096-1523.23.5.1427

Trainor, L. J., & Adams, B. (2000). Infants' and adults' use of duration and intensity cues in the segmentation of tone patterns. *Perception & Psychophysics, 62*(2), 333-340. doi:10.3758/BF03205553

Trainor, L. J., & Corrigall, K. A. (2010). Music acquisition and effects of musical experience. In M. R. Jones, R. R. Fay, & A. N. Popper, *Music Perception* (Vol. 36, pp. 89-127). New York: Springer. doi:10.1007/978-1-4419-6114-3_4

Trainor, L. J., & Trehub, S. E. (1992). A comparison of infants' and adults' sensitivity to Western musical structure. *Journal of Experimental Psychology: Human Perception and Performance, 18*(2), 394-402.

Trainor, L. J., & Trehub, S. E. (1994). Key membership and implied harmony in Western tonal music: developmental perspectives. *Perception & Psychophysics, 56*(2), 125-132.

Trainor, L. J., & Unrau, A. (2012). Development of pitch and music perception. In L. Werner, R. R. Fay, & A. N. Popper, *Human Auditory Development* (Vol. 42, pp. 223-254). New York: Springer. doi:10.1007/978-1-4614-1421-6

Trainor, L. J., Lee, K., & Bosnyak, D. J. (2011). Cortical plasticity in 4-month-old infants: specific effects of experience with musical timbres. *Brain Topography, 24*, 192–203. doi:10.1007/s10548-011-0177-y

Trehub, S. E. (2010). In the beginning: a brief history of infant music perception. *Musicae Scientiae*, 71-88.

Winkler, I., Háden, G. P., Ladinig, O., Sziller, I., & Honing, H. (2009). Newborn infants detect the beat in music. *Proceedings of the National Academy if Sciences, 106*(7), 2468-2471. doi:10.1073/pnas.0809035106

APPENDICES

APPENDIX I
Informed consent form

Solicitação de colaboração

Durante a semana de 26 a 30 de Maio, realizar-se-ão exercícios de perceção musical (audições) que visam alargar o conhecimento sobre a forma como a música é apreendida nas diferentes idades. Estes exercícios farão parte de um estudo realizado pelo Laboratório de Fala da Faculdade de Psicologia e de Ciências da Educação da Universidade do Porto num projeto que investiga a perceção musical em diferentes idades e a sua relação com algumas características individuais.

Seria de todo o interesse para esta investigação poder relacionar os dados destes exercícios com algumas informações biográficos (peso e tempo à nascença) do seu educando. Os dados serão recolhidos com o conhecimento e autorização da Direção do Agrupamento e Coordenação da Escola e serão tratados de forma anónima e confidencial.

Assim, solicitamos a sua autorização e colaboração neste estudo. Para tal, indique as seguintes informações relativas ao seu educando:

Nome: ____ Turma: _______

Data de nascimento: ________/___/___

Com quantos(as) meses/semanas nasceu? ____________________

Peso à nascença: _______________ Kg

Aulas de música: Sim ___ Não: ___

Aulas de música na escola: ____

Aulas de música fora da escola: ____

Nº de anos de frequência de aulas de música na Escola: ____

Nº de anos de frequência de aulas de música fora da Escola: ____

____

O encarregado de educação

Obrigado pela colaboração!