Unravelling our capacity for music

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Brief summary

Unravelling our capacity for music
Musicality is an ability that nearly all human beings possess: a set of traits that allows us to appreciate music. This research aims to identify these constituent traits by means of a series of listening experiments in the form of engaging memory-based games.

Het ontrafelen van onze capaciteit voor muziek
Muzikaliteit is een aanleg waarover wij mensen vrijwel allemaal beschikken: een verzameling eigenschappen die het ons mogelijk maken van muziek te genieten. Dit onderzoek richt zich op het in kaart brengen van deze eigenschappen door middel van een reeks luisterexperimenten in de vorm van aantrekkelijke geheugenspelen.

Summary

This research is about 'musicality'. It aims to identify which set of music cognitive traits gives rise to our ability to perceive and appreciate music. We will approach musicality as a multicomponent phenomenon, aiming to decompose the capacity for music into its constituent components. The focus will be on melody and rhythm cognition, with special attention to their interaction with timbre. We hypothesize that everyday listeners are attentive to the relative aspects in *all* dimensions of the musical signal, suggesting 'contour perception' (a sensitivity to the relations between successive sounds, rather than their absolute values) to be widespread and fundamental to music cognition.

In a series of listening experiments, we will test this 'contour hypothesis' by disentangling the contributions of melodic, rhythmic and timbral contours to the recognition of familiar music. Next to lab-based and field-based listening experiments, we will develop engaging online games (i.e. citizen science) to be able to probe musicality phenotypes on an unprecedented scale (aiming at 1M+ participants from different societies). This will allow us to properly characterize musicality and reveal its phenotypical variation between individuals and across societies. The latter allows us to differentiate between cognitive, biological and environmental aspects of musicality. The research will contribute to a 'phenomics of musicality', providing a robust and relatively unbiased way of identifying the human capacity for music. Overall, the project serves as an important first step in a larger research programme, that has the aspiration to lay a new, interdisciplinary foundation for the study of musicality.

Keywords: music cognition, comparative musicology, cross-cultural, individual differences, timbre

Introduction

Over the years it has become clear that **we all share a predisposition for music**[1], just like we have for language[2]. Even those of us who can't play a musical instrument or lack a sense of rhythm can **perceive and enjoy music**[3–7]. We will refer to this unique predisposition – in all its complexity – as *musicality*, defined as a natural, spontaneously developing set of traits that are based on and constrained by our cognitive abilities and its underlying biology. As such, *music* – in all its diversity – can be defined as a social and cultural construct that is built *on* this musicality. This distinction might appear trivial, but it **demarcates an important shift in music research** from studying the structure of music (across cultures and species) to studying the structure of musicality, i.e. the **cognitive and biological capacities** that can give rise to music[8].

To illustrate this distinction: Melodies vary in numerous ways across cultures, for example, in the structure of their underlying scales[9]. Yet, as far as we know, people in every culture can recognize a melody when it is transposed up or down in pitch. Thus, the ability to recognize a transposed melody (relative pitch) is part of our cognition, and can be argued to be a fundamental component of our capacity for music[10].

This important shift in research is also reflected in the book titles of the seminal *The Origins of Music*[11] and the more recent *The Origins of Musicality*[12]. The latter publication has laid the foundation for an ambitious and interdisciplinary research agenda of which the **current proposal is an important first step**.

The research agenda has two main aims: a) to **identify the multicomponent structure of musicality** and b) to **differentiate between cognitive, biological and environmental aspects of musicality**. These aims will be addressed by focusing on two research questions: **Q1**) What are the core cognitive components of musicality? And **Q2**) What are the biological and environmental factors contributing to musicality?

Q1) What are the core cognitive components of musicality?

Though we are learning more and more about music perception and cognition[3–5], the cognitive basis of our capacity for music remains unclear[8]. One possible way of unravelling this capacity is by using a **multicomponent approach,** decomposing musicality into its constituent components using a 'divide and conquer' strategy (See Table 1).

Promising candidates for these constituent components, that have been proposed in the recent literature, are, relative pitch, recognizing a melody separately from the exact pitch or tempo at which it is sung or played, and beat perception, hearing regularity in a varying rhythm. Without these cognitive traits it is, arguably, impossible to perceive, make and enjoy music[12]. However, there are also several candidate components about which there is **considerable debate**, such as consonance, metricality and tonality[13–15], the latter being considered by some to be a result of mere exposure to Western music, and hence have a strong cultural bias[16,17] (See **Q2**).

Although *relative pitch* and *beat perception* are already observed in young infants[6], there is no consensus on which relationships between tones are being preserved, i.e., on **what is extracted from the musical signal by the listener** and maintained in memory**.** It could be the intervallic structure (*pitch interval*) of the melody (e.g., a third up, a semitone down, etc.), the *melodic contour* (i.e., the overall change of direction of the melody, with the size of the intervals being less relevant), or other variable aspects of the acoustic sequence, such as the *spectral contour* (see Table 1). Since most studies on pitch perception are restricted to pure tones or synthetic sounds with a static timbre[18,19], they are unable to disentangle these alternative interpretations. In short: what makes two melodies similar (i.e. *perceptually invariant)* is unclear for ecologically-valid and spectrally rich stimuli (i.e. real music).

Therefore, the current project will give **special attention to timbre**, an aspect of musical sound that is often considered to be secondary in music research[20,21]. However, at least one perceptual study[22] has shown that loudness and brightness contours (aspects of timbre) are nearly as useful as pitch contours **in recognizing familiar melodies**. This suggests that **'relative listening'** might well be more flexible than previously thought, and **not solely dependent on pitch.**[a] Next to pitch (*melodic contour*) and timbre (*spectral contour*), listeners might even perceive *rhythmic contour*, i.e. a sequential pattern of relative shorts and longs without a precise notion of their proportional relationships[23]. Based on these observations **we hypothesize that everyday listeners are attentive to the relative aspects in *all* dimensions of the musical signal**, suggesting contour perception to be widespread and fundamental to music cognition.

In a **series of listening experiments** (in the **lab**, the **field** and **online**) we will test this **'contour hypothesis'** by disentangling the contributions of melodic, rhythmic and timbral contours to the recognition of familiar music (i.e. familiar to one's own culture). For this, we will combine a set of **state-of-the-art signal processing methods** with **memory-based listening experiments**. The former will allow us to identify which acoustic cues are crucial to music cognition, the latter will reveal which aspects of the musical signal are perceptually salient and/or cognitively relevant (See Methodology for details).

	Candidate components of musicality
Melody	Relative pitch (pitch interval)[18,24,25]
	Absolute pitch (fundamental frequency)[7,26]
	Melodic contour (change of pitch direction)[18,27]
	Tonal encoding of pitch (*tonality*)[13,28]
Rhythm	Isochrony perception[29,30]
	Beat perception[30,31]
	Rhythmic contour (grouping)[23,32,33]
	Metrical encoding of rhythm (*metricality*)[30,34]
Timbre	Timbre perception[21,35]
	Consonance perception (*harmonicity*)[15,17]
	Spectral contour (change of timbre)[36,37]

Table 1. *Potential candidates for a multicomponent model of musicality, as suggested in the recent literature. Most scientists agree that 'relative pitch' and 'beat perception' are fundamental; Most other components are under considerable debate. The current proposal will focus on the components marked in bold (see main text).*

Q2) What are the biological and environmental factors contributing to musicality?

Both scholars and scientists agree that music appears in most, if not all cultures, from the oldest civilizations of Africa, China, and the Middle East to the countless cultures of today's world[38]. No culture has yet been found that does not have music[13]. Still, some music researchers are **skeptical about the biological foundations of musicality**[39,40]. In their view, every form of music in every culture is unique and is determined by human, social, and cultural conventions. However, over the past few years, more and more systematic research has been conducted on the similarities and differences between music from around the world, research that brings us closer to being able to separate the biological and cultural contributions to musicality.

A recent example is the work of Savage *et al.*[9], that classified a large collection of world music recordings according to a long list of features drawn up by ethnomusicologists, in an attempt to reveal '**statistical universals'**[41]. The authors found that, in these recordings, melodies are usually comprised of a limited set of discrete pitches (seven or less) that form part of a scale, and are divided into unequal and relatively small intervals. Most of the music also had a regular pulse (an isochronous beat), usually with two or three subdivisions, and a limited

[a] Interestingly, a recent study in avian cognition was able to show that songbirds primarily use *spectral contour* to recognize melodies, instead of absolute pitch[36]. One could say that songbirds are listening to a melody as if the stimulus were a *klangfarbenmelodie*[70]. This kind of relative, 'spectral listening' has been observed earlier by music theoreticians[71] and led Western composers, from Edgard Varèse to Kaija Saariaho, to give timbre an important place in their compositions.

set of rhythmic patterns. Another example is an impressive study by Mehr *et al.*[13] that applied the methods of data science to a collection of audio recordings and ethnographic texts to provide a **systematic overview of universal principles** underlying sung music. Despite quite some diversity, this study also found striking similarities in a representative sample of world music, similarities that are suggestive of several 'universals', including tonality.

However, both studies base their findings on the **structural aspects** of world music (classified by music professionals or music information retrieval techniques), and **not so much on the underlying capacity for music**: how music is perceived by an everyday listener (as is the topic of this proposal). In addition, when perceptual judgements were included in these studies, these were performed by Western experts and as a consequence suffer from a **sampling bias**[42]. And lastly, it is important to note that focusing on 'universals' is not enough to understand the capacity for music. In fact, when one investigates musicality as a set of traits with a potential biological basis, it is important that one moves **beyond universality** and recognizes the **value of studying variability** between individuals and across societies[43]. Individual differences can reveal the amount of flexibility, c.q. cognitive constraints acting on musicality. Differences between groups or societies can reveal the environmental influences on our capacity for music.

We will examine this flexibility and environmental influences by asking naïve (musically untrained) everyday **listeners from different cultures, societies and environments** to make **perceptual judgements** of music familiar to their own culture (instead of having Western experts judge the music from a variety of cultures)[44].

We will use **musical memory** (i.e. the recognition of a musical fragment) as an important tool to capture and understand the **phenotypic variability** discussed above, using it as a measure of what is **perceptually salient** and/or **cognitively relevant** in familiar music. A **memory measure** has the added advantage that 1) it is an aspect of cognition that is not culturally biased, 2) the method allows for the use of ecologically valid stimuli (i.e. real music), 3) memory performance appears to be independent of musical training (i.e., naïve, everyday listeners do equally well as compared to trained musicians for familiar music), 4) listeners appear to have significantly better memory performance for culturally familiar music, and 5) a better memory performance indicates a greater understanding of the nature of the musical stimulus[45,46]. This will allow us to map out more precisely **what components of musicality are shared** (and potentially of a universal and biological nature) and **which differ and might be culturally learned** (brain plasticity) **or an adaptation to the environment.**

Methodology

The project consists of five work packages (**WP1-5**). **To address Q1**, in **WP1** we will develop, test and evaluate a set of neurocognitively plausible transformation tools to generate the stimuli that will be used in the memory-based listening games of WP2. In **WP2** a set of intrinsically motivating listening games will be developed with a solid psychometric basis. The resulting memory-based games will be used **to address Q2**, in a field study contrasting WEIRD[42] Dutch listeners with a non-WEIRD hunter-gatherer community (**WP3**), and in a large-scale online study comparing everyday listeners from a variety of geographical regions, including Europe and China (**WP4**). Finally, the results will be evaluated in terms of the projects' main aims, and discussed in relation to the neighboring disciplines (**WP5**).

WP1: Stimuli construction and decomposition

In WP1 we will customise and evaluate a set of signal processing tools that allows for independently manipulating the pitch, temporal and/or spectral dimensions of an existing audio recording of a musical fragment. To **separate pitch from timbre,** we will use **noise vocoding**[47], an acoustic technique that removes pitch cues from an audio signal, but preserves overall spectral shape and contour. To **separate timbre from rhythm** (and vice versa), we will use **spectro-temporal modulations (STM)**[48], a mathematical framework that unifies AM and FM filtering.

These state-of-the-art methods provide a **computationally rigorous and neuro-physiologically plausible** approach to the cognitive decomposition of acoustical cues, methods that go beyond the traditionally stereotyped cues of acoustic phonetics or those used in music information retrieval (MIR). STM has been used successfully in disentangling the neurocognitive processing of music versus speech[48], and noise vocoding was recently shown to be pivotal in the understanding of melody recognition in songbirds (see footnote a)[36].

Next to independently degrading the temporal and spectral dimensions of a sound, STM was also shown to be effective in **separating linguistic from melodic information**.[b] This will allow us to probe in how far it is the melody (and not the words) that make a familiar song **recognizable**, and whether there are **individual differences** in attending to the melody and/or words. A series of relatively straightforward categorization experiments (based on the work of [49]) will provide insight in the effectiveness of this measure in the current context, and how best to incorporate it in the other WPs using the more complex matching pairs design.

In summary, a novel combination of methods will be used to parametrically degrade each item in the memory-based games selectively, such that we can test the **impact of contour information** (in the pitch, rhythm and timbre dimension) on the **recognition of a musical fragment** in a memory task.

WP2: Design and evaluation of memory-based online games

In WP2 we will build on our **extensive experience** in developing internet-based listening experiments and intrinsically motivating listening games[50–52]. A recent example of such an online game is '**Hooked On Music**'[c], a citizen science project that was developed to uncover **what makes music memorable**[52]. We will use this game format to select for each of the different listener groups (see WP3 and WP4) which musical fragments are most recognizable within a group, resulting in several corpora of culture-specific, familiar and easy to recognise musical fragments. These corpora will be used in several **variants of the matching pairs game**, including an **objective (MP1),** a **subjective (MP2)**, and an **adaptive version (MP3)**.

Version one (**MP1**) is much like Memory, the card-game most children love to play. In this version, two melodies have to be judged as being the same, in a context of several competing alternatives. Note that this game variant has to make use of a 'gold standard' to be able to rate a response as correct (or not).[d] As such, the game is only indirectly able to reveal the variability that we are interested in.

Hence, a variant of the game (**MP2**) will be 'subjective', without being forced to decide beforehand what is a correct response. This allows for exploring the underlying regularities that the 'objective' version has to ignore (e.g., to avoid the WEIRD[42] notion that two melodies are different because one of the pitches is different). In the 'subjective' version items can be similar in different aspects. As such, more than one pair might be correct. Instead of 'correctness', we will use alternative rating measures to be able to give feedback to the player, using, for example, internal consistency or some form of peer-judgement. The responses will reveal which aspects of the musical signal are more prominent, salient or easier to remember in the context of several alternatives.

The final variant of the game (**MP3**) will dynamically adapt to the level of the player, resulting in a robust and, in terms of duration of the experiment, efficient game useful for probing musicality on a large-scale. It will adjust the parametrized degradation of the stimuli (WP1) and the difficulty of the game, depending on how well the player performs (using IRT and CAT; See below). This variant will introduce some additional challenges to the design of the game, as well as the psychometric analyses of the results. However, for both aspects several methods are available that are well understood (e.g., *computerized adaptive testing* (CAT))[53,54].

In addition to developing variants of the matching pairs game, an **important contribution of WP2** will be to support the novel games with a solid **psychometric basis** using *item response theory* (IRT)[55]. This method

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[b] Albouy *et al.* showed that degradation of the temporal dimension impaired sentence recognition, but not melody recognition; and degradation of the spectral dimension impaired melody recognition, but not sentence recognition[49].

[c] 'Hooked On Music' was played a total of 2 million times, by nearly 200.000 participants in more than 200 countries.

[d] Such a *gold standard* is used in virtually all musical aptitude and musicality tests to rate the responses. However, 'correctness' is typically based on Western/WEIRD judgements.

will allow us to properly analyse the results and to distinguish between, for instance, perceptual sensitivity, difficulty of the stimulus, guessing behaviour, and the role of attention[53].

Next to variants of the matching pairs game, we will explore **alternative game structures** that are effective in probing the constituent components of musicality[50,56,57].

WP3: Cross-cultural field study

This field study will be conducted in a small-scale foraging community in the rainforest of Congo-Brazzaville (2° 28 N, 17° 26 E), an established study site[58]. The **Mbendjele BaYaka people**, that live in this region, are well known for their strong affection for music[59]. Members of this community make music during many daily activities by singing, drumming or, for example, rhythmic water scooping, and are thought to have a distinctive sense of style in which **'music is more central to culture than language'**[60]. The latter statement suggests that, in this society, words might be less important than the musical aspects of a song. We will probe the perceptual sensitivities to the musical and linguistic aspects of familiar music, and see how they might differ as compared to Western listeners.

To study musicality in this community, we will use familiar children songs and/or work songs that will be transformed (WP1) and presented in a portable version of the matching pairs game (WP2), using one or several tablets. In the Netherlands, a **matched group of Dutch listeners** (matched by age, gender, etc.) will be studied for comparison, using a corpus of well-known Dutch children songs. Clustering the listener groups by age will give an additional insight on the role of musical experience[25].

As an alternative to a tablet version of the matching pair game, we will develop a set of **physical, sound producing 'cards'** on which the individual musical fragments can be downloaded (e.g., *Cards that Talk*). This will allow for playing the game in a more common setting, that allows for activities like card sorting, turn-taking and other social aspects, that might add to the fun of playing the game. In addition, we will explore the possibilities of **several alternative card and/or children's games** that the Mbendjele are familiar with, and that invite for music-related activities. We will later replicate these games in the Dutch setting at the UvA for comparison.

WP4: Cross-cultural online study

In WP4 we will comparatively study musicality in a variety of **geographical regions with ready access to the internet** and with a **rich culture of popular music**. We will start by contrasting European listeners with listeners from China, adding other regions later on.

For the **European version** of the game we will use a corpus of popular music (drawn from Top2000 'greatest songs of all time' list) from which we will select up to a hundred specific fragments that are easiest to recognise and/or remembered (i.e. 'catchy'), using the 'Hooked on Music' infrastructure. For this selection-phase we will invite different subgroups of European participants that participated in earlier online studies, and who indicated to be musically untrained listeners.[e]

For the **Chinese version** of the game a corpus consisting of Chinese popular music will be used. A representative selection of memorable songs is currently being assembled in the context of a PhD project by Xuan Huang.[f] For the fragment selection phase we will invite Chinese participants that actively participated in earlier online studies (see Chinese version at footnote e) and members of the ILLC student community.

Both European and Chinese corpora will be transformed using the techniques described in WP1. Before recruiting large-numbers of participants via the social media and related internet fora, the **different variants of matching pairs game will be extensively piloted**, testing alternative user-interface designs, game flow, levels of difficulty, and overall attractivity.

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[e] See http://www.mcg.uva.nl/exp3[56].

[f] This ongoing PhD project compliments the current proposal in that it focusses on the *structure of music* (instead of the capacity *for* music). It will allow us to disentangle the musical features that can be identified acoustically (using MIR), from those that are of a perceptual and/or cognitive nature: the topic of the current proposal.

The final version of the game will be **launched in a coordinated fashion**, preparing a joint press release (including teasing video material for the social media) in close collaboration with news media and interested science museums (e.g., MOSI, UK; Nemo, NL). Depending on the results and success of the online game, we will extend the invitation to participants to other regions in East Asia (including Taiwan and Japan) as well as regions in North-America, South America (Brazil and Argentina) and Central-Africa (cf. WP3).

WP5: Synthesis; Towards an integrated theory of musicality and its origins

In WP5 we will **evaluate the overall results** and integrate the obtained insights from the proposed and other studies into a synthesising review. We will combine the most recent evidence from both cross-cultural and cross-species studies, **reaching out from music cognition to related fields** like comparative musicology[61], evolutionary musicology[45], and cognitive biology[62].

To achieve this broader synthesis, we will organize an **international symposium** (see Table 3). Its aim will be to relate our findings to those of other fields, and to jointly explore the implications of the existing and novel findings for **cognitive theories of the origins of musicality**. Such a broader synthesis will also incorporate findings in other taxa (most notably primates, pinnipeds, and birds), considered crucial to researchers concerned with the biological basis of musicality[8]. This comparison will further our insights in which features of musicality are exclusive to humans (or to other species) and which are shared between humans and non-human animals. It will allow us to address questions like: How widespread (evolutionary ancient) is the use of pitch to recognize tone sequences? Is spectral contour an evolutionary older, more stable alternative? Why do humans gravitate to pitch for melody recognition? Is using pitch to recognize melodies in part a cultural phenomenon? Which aspects of rhythmic perception are shared across species and what is the link to other aspects of their cognition (such as vocal learning)? In the end we aim to address the questions: How can the constituent components of musicality best be combined in a cognitive and biologically informed theory? And how does this theory further constrain evolutionary theories of musicality?

Innovative character

Roughly 15 years ago, the Music Cognition Group (MCG) pioneered the use of **internet-based techniques for probing music perception**[56,63]. Though the results were initially not considered for review by quality journals such as *Cognition* (owing to a principled position against Internet experiments[63]), the MCG succeeded in convincing their peers that these methods are an **important technique and complementary to lab-based experiments**.[g] However, one of the continuing challenges of internet-based listening experiments is that of **attracting a suitable participant group** that is willing to **seriously engage** in online experiments. Since our first online experiments, MCG developed various techniques to make such experiments attractive and **intrinsically motivating**, avoiding monetary rewards (like Amazons *Mechanical Turk*) or other motivations that could interfere with the quality of the responses. The memory games proposed in WP3 and WP4 are a natural consequence of this earlier work, and allow us to **probe musicality and its variability** in a variety of geographical regions on an **unprecedented scale**. Next to properly characterizing phenotypic variability, this scale will allow us to define a musicality measure that can, at least in principle, provide the large amounts of phenotypic data that are needed to search for correlations with variations at the genetic level (e.g. using genome-wide association scans) and environmental variables[43]. All this will further tighten the cross-fertilization between the fields of music cognition, musicology, anthropology, genetics and cognitive biology.

Urgency and relevance

The origins of musicality is a topic that has been put on the international agenda by an interdisciplinary group of researchers attending the 2014 Lorentz workshop in Leiden, NL, organised by MCG and prof. Carel ten Cate

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[g] After all, if an effect is detected online, in spite of all kinds of real-world variance and technological variability, this provides strong support for the reliability of that effect[63].

(Advisory Board). It resulted in a widely agreed upon **research agenda on musicality**[8,12] that the current proposal is gratefully building on.

In 2019, MCG and prof. Simon Fisher (Advisory Board) organised a KNAW Colloquium on musicality and genomics,[h] elaborating on an important part of the research agenda that was set at the Lorentz workshop[43], focussing on the **phenomics and genetics of musicality**. A follow-up symposium is planned for 2021, during the Neurosciences and Music Conference in Aarhus, DK, just before the foreseen start of the current project.[i]

In short, these two meetings have generated an **international visibility** and **momentum,** that the current proposal, when granted, will be able to take advantage of.

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[h] See www.mcg.uva.nl/musicality2019.

[i] See Provisional program NMVII.

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