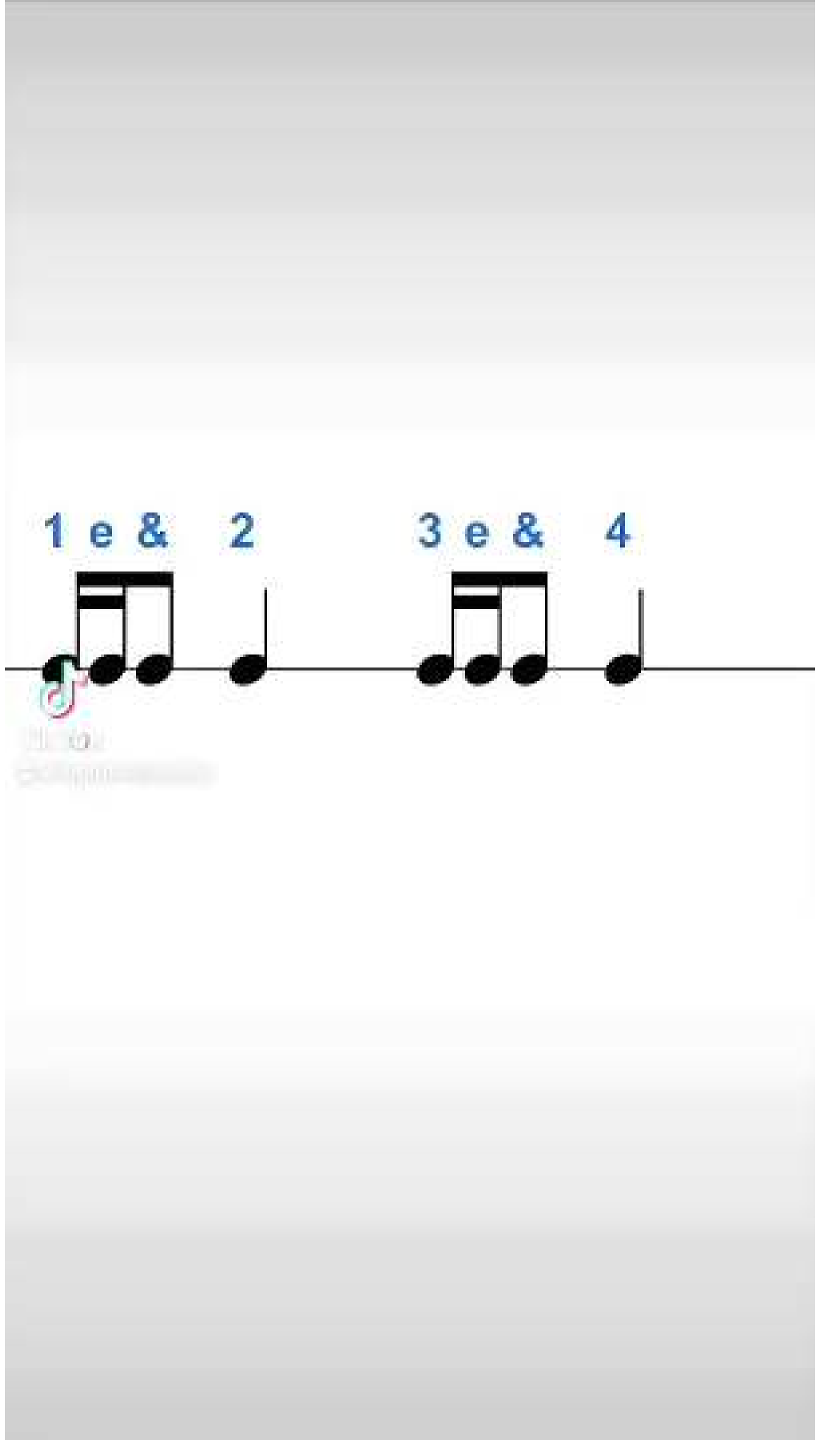
第八讲

脑与认知科学

脑与认知加工：音乐

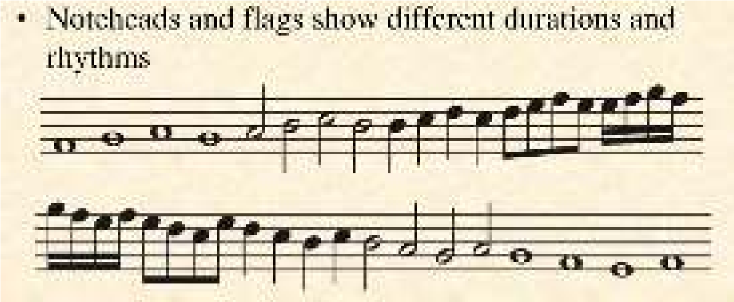
授课人：南云教授
北京师范大学｜心理学部

一起来拍手！



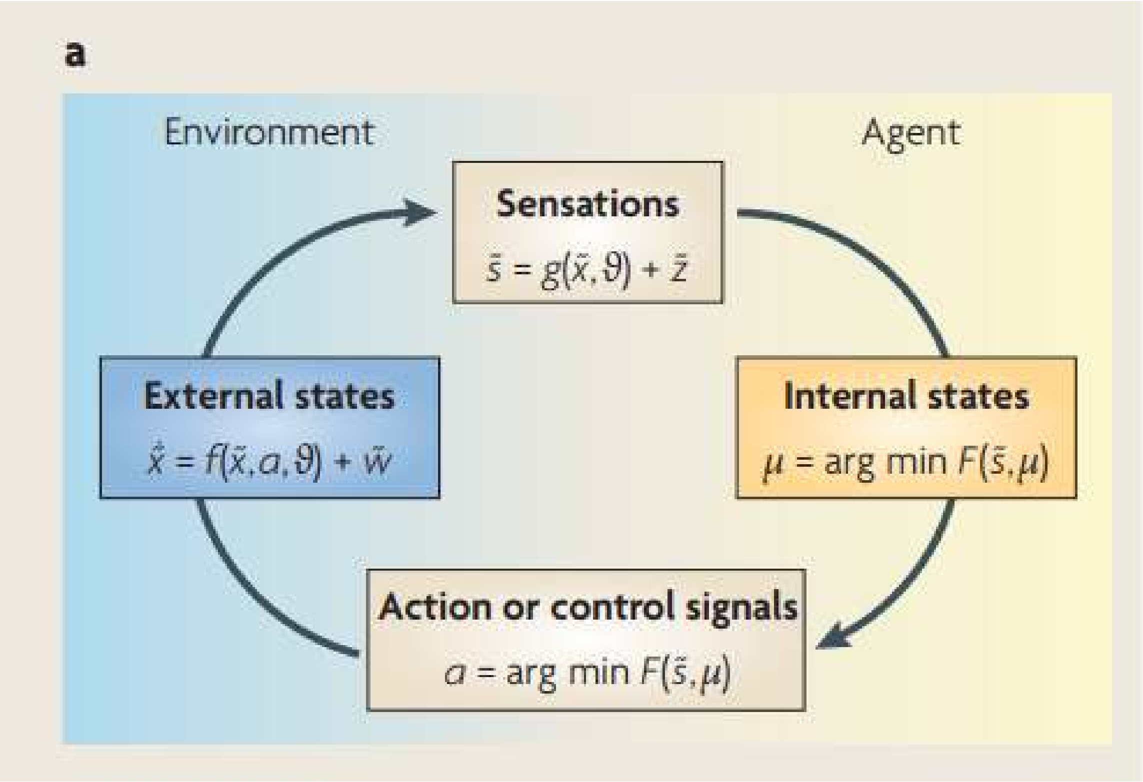
什么是音乐?

- **Music** is an art form and cultural activity whose medium is sound and silence.
- Perceptually discrete elements, organized into hierarchically structured sequences according to “well-formedness” rules.
- 音高： pitch (melody and harmony),
- 节奏： rhythm (tempo, meter, and articulation),
- dynamics (loudness and softness),
- timbre
- texture ("color" of a musical sound).

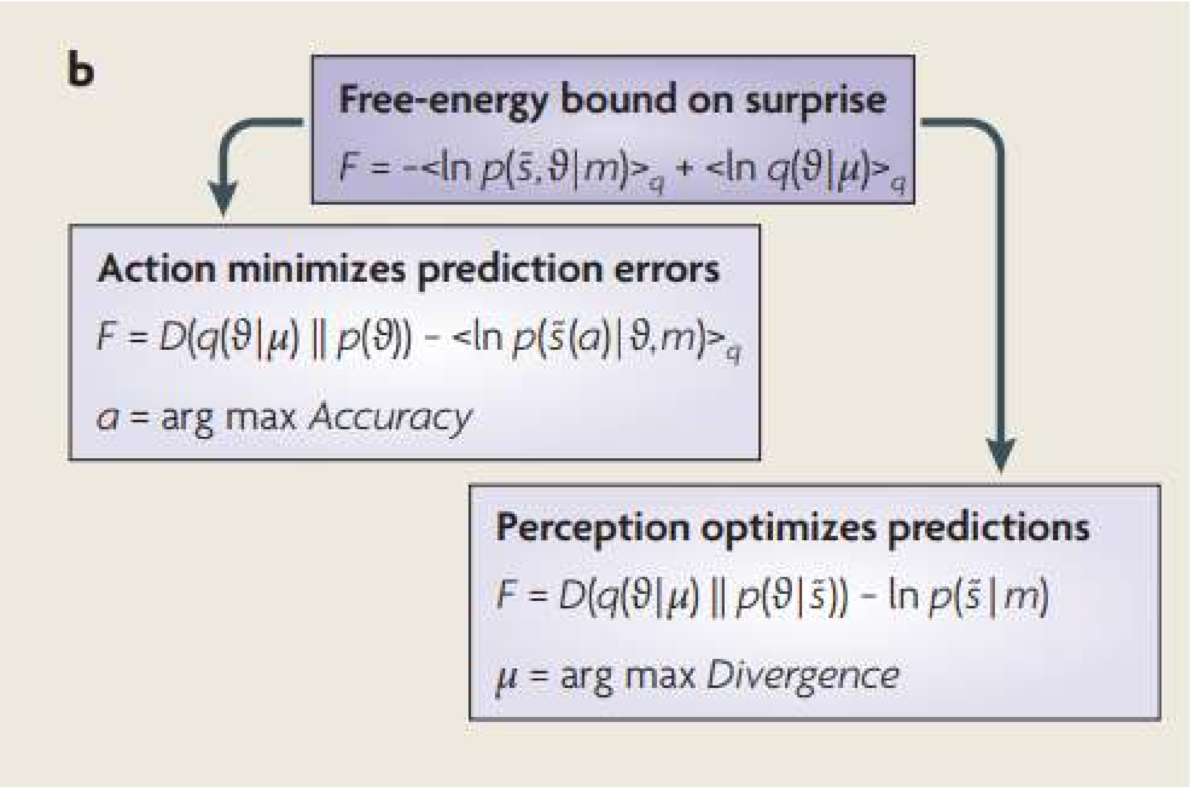


自由能原则（预期加工）脑的基本工作原理之一

大脑不断地预测外部世界



感知、行动、学习均属于递归贝叶斯推理过程，
脑试图减少对于感知输入的预期误差

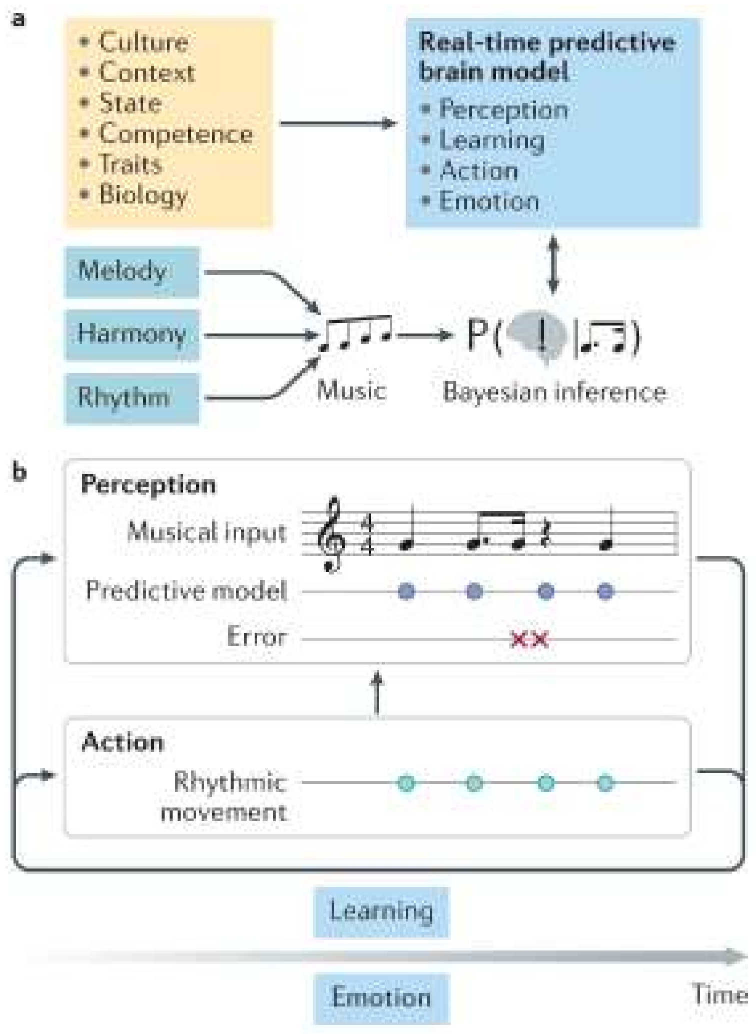


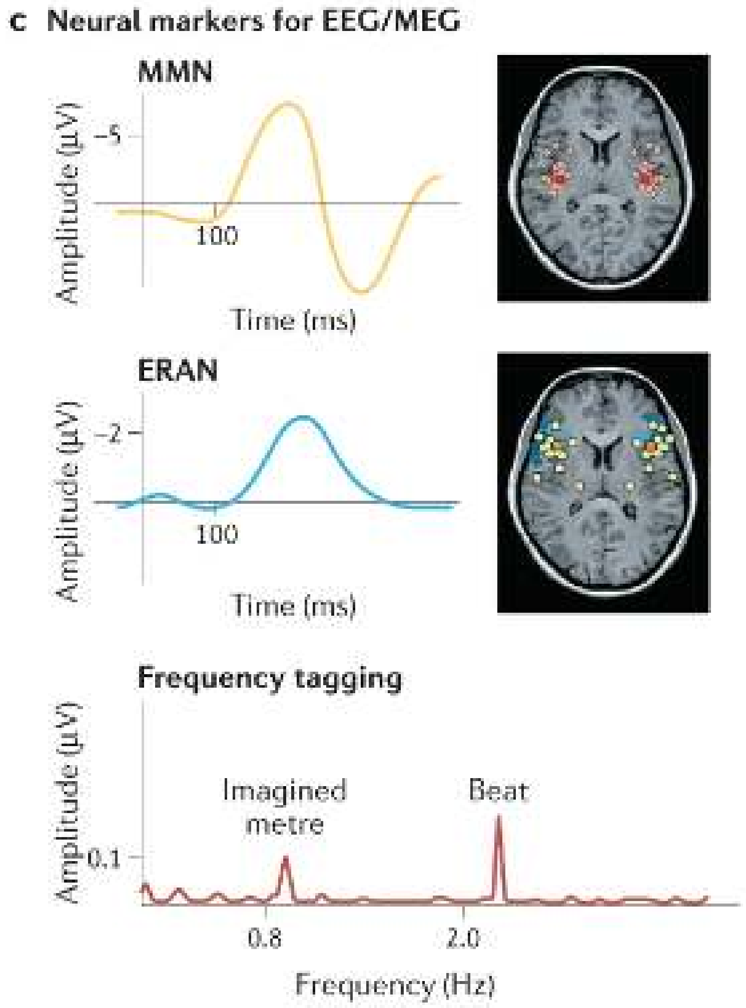
Friston et al., 2010 *Nat. Rev. Neurosci.*

现场实验，她在说什么？

Patricia Kuhl @ University of Washington
http://auditoryneuroscience.com/?q=McGurkEffect

音乐加工：研究脑预期加工的模型



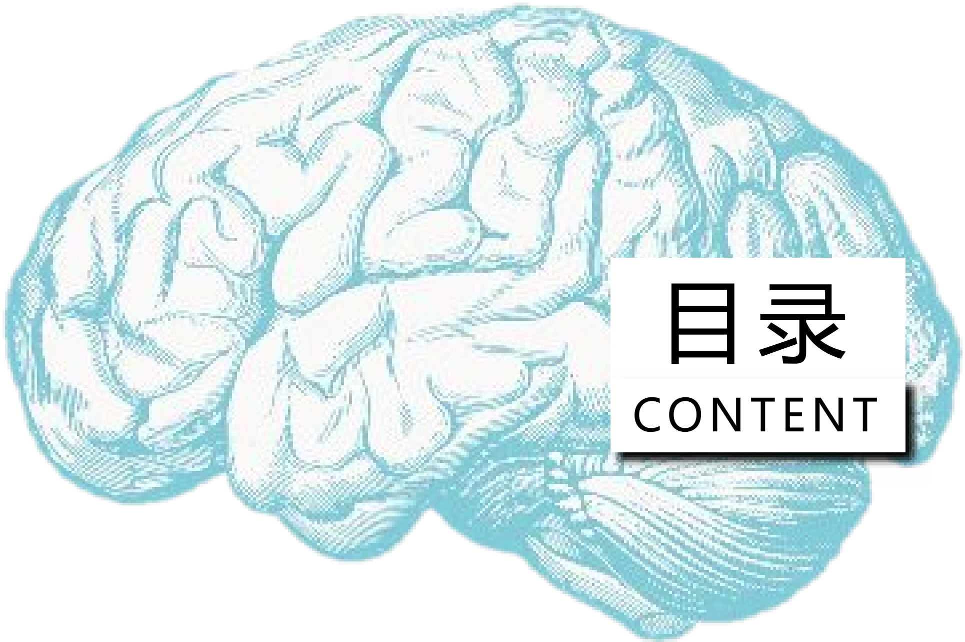


Vuust et al., 2022 *Nat. Rev. Neurosci.*

本章关键知识点

1、音乐是人脑的创造产物，同时可以影响人的心智发育。

2、音乐与多种高级认知加工共享神经网络。



目录
CONTENT

一、音乐的起源

音乐并非人类独有

目前地球上有5400种能唱歌的动物

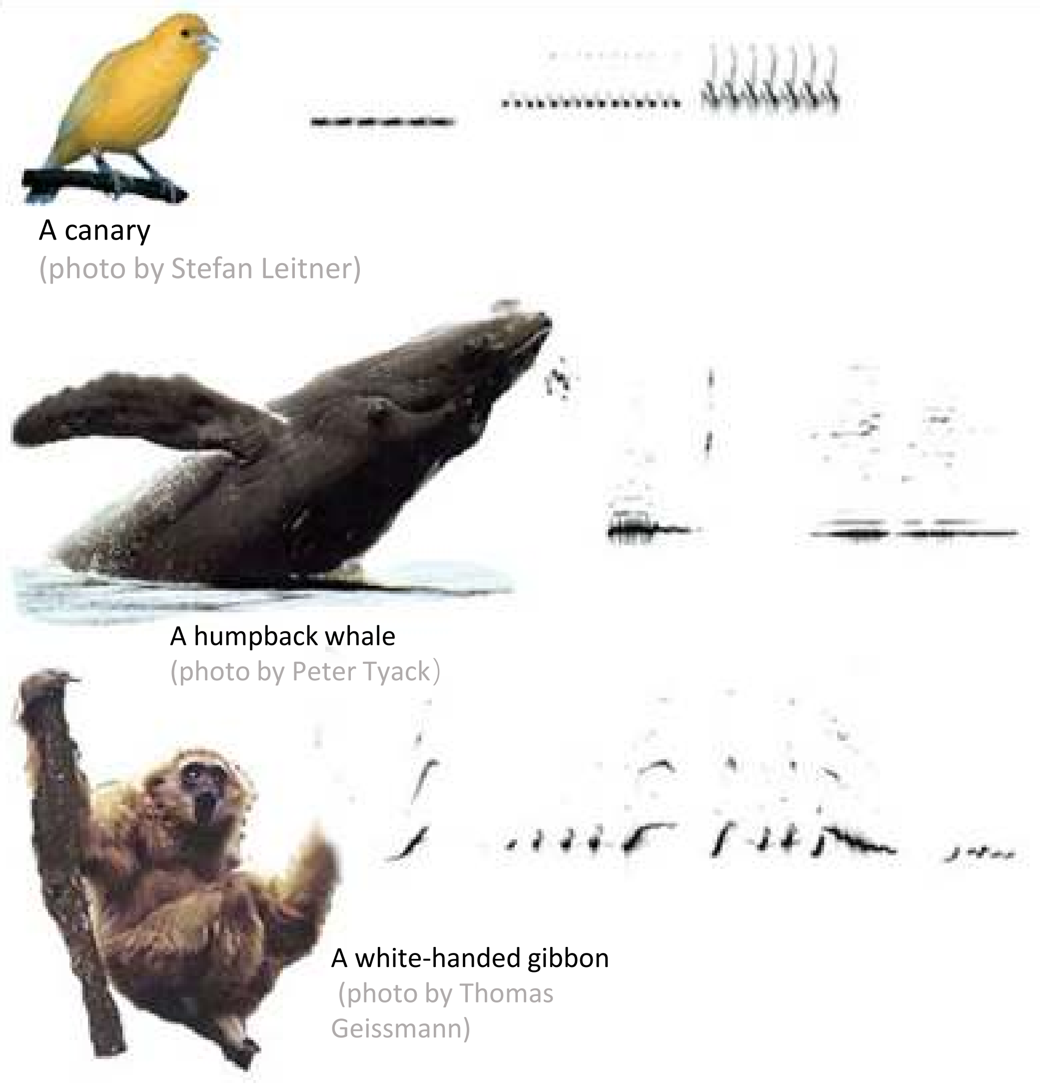
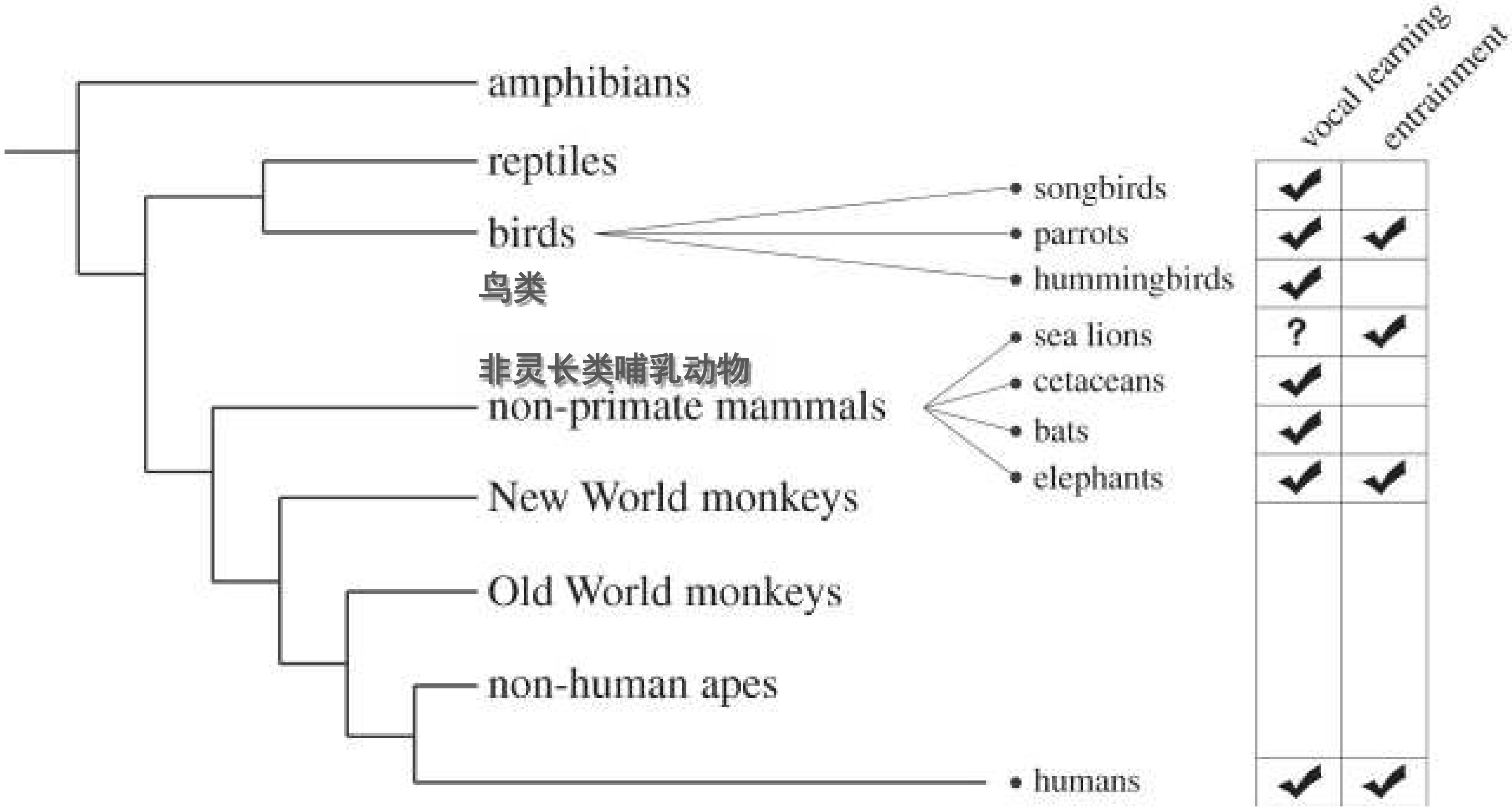


Figure from http://www.nature.com/neuro/journal/v6/n7/fig_tab/nn1080_F3.html

演化树:
可以唱歌与随节拍舞动的物种

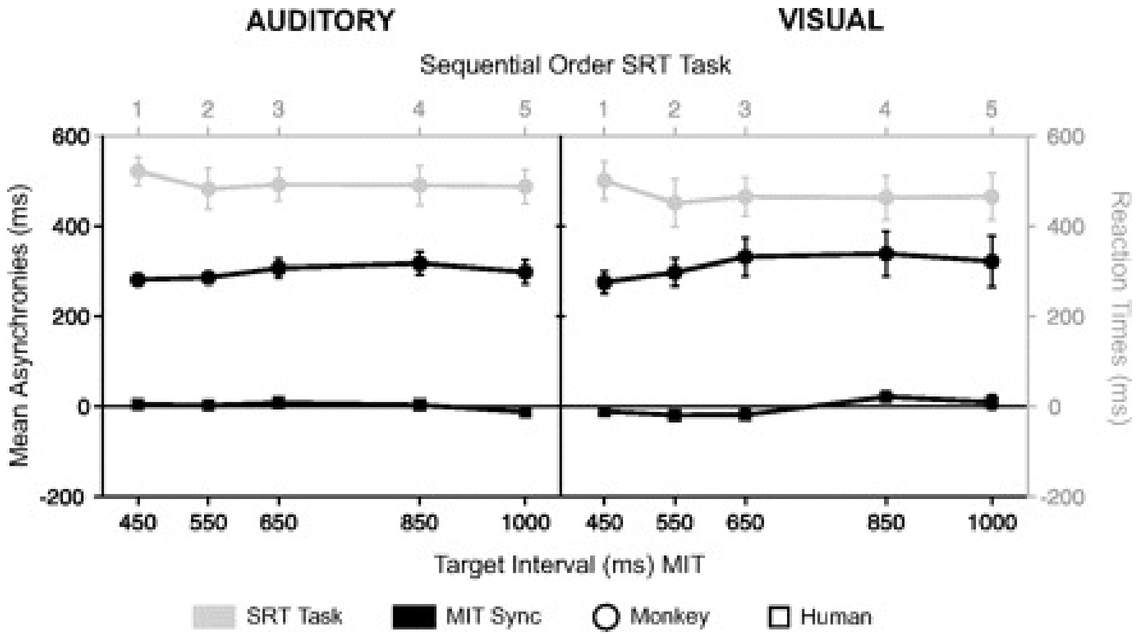


Snowball
The dancing cockatoo

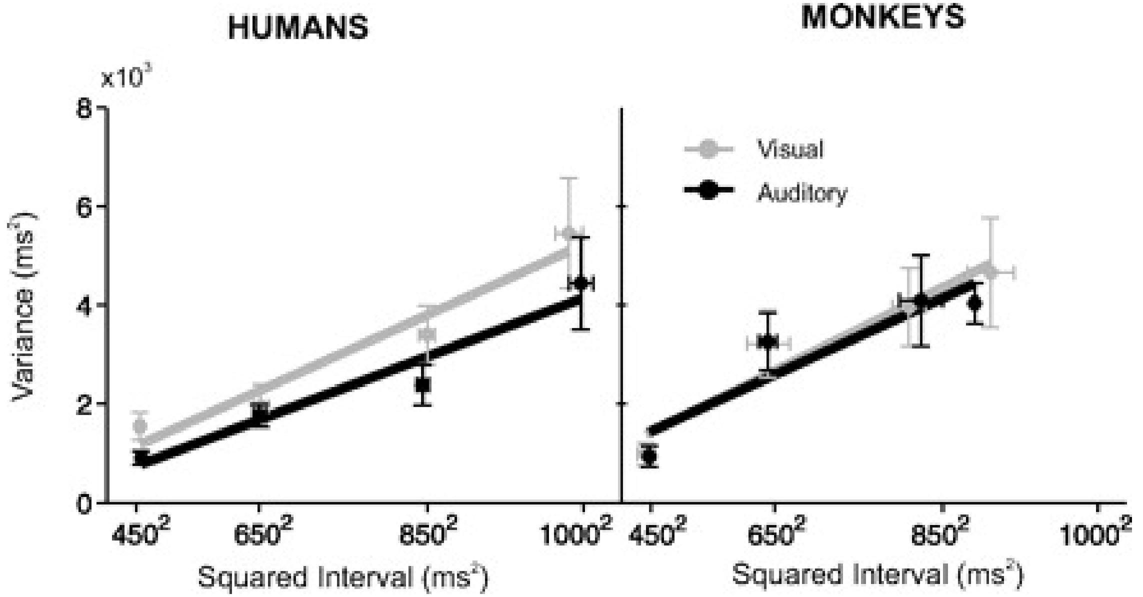
Hoeschele et al., 2015

节奏加工的独特之处：恒河猴与人的对比

人在听觉，尤其是视觉通路上tapping的都是先于刺激开始时间；而猴则是比刺激开始时间在两个通路都要晚约300毫秒。
但猴对照单个interval的tapping任务时，连续tapping还是表现出了更低的反应时（最少需要11个月学习）。



单个interval的tapping任务时，人与猴表现相似（需要4个月学习）



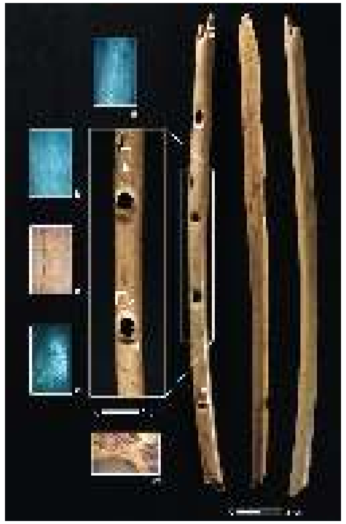
Zarco et al., 2009 *J Neurophysiol.*

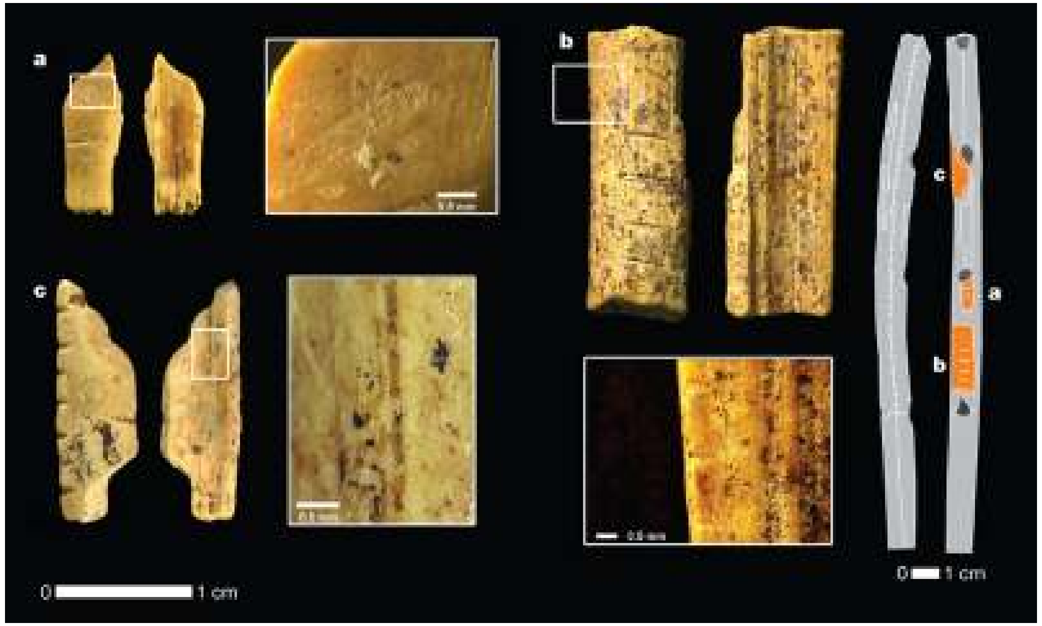
考古学的发现

中国最早的乐器：贾湖古笛（8000~9000年前）

Zhang et al., 1999

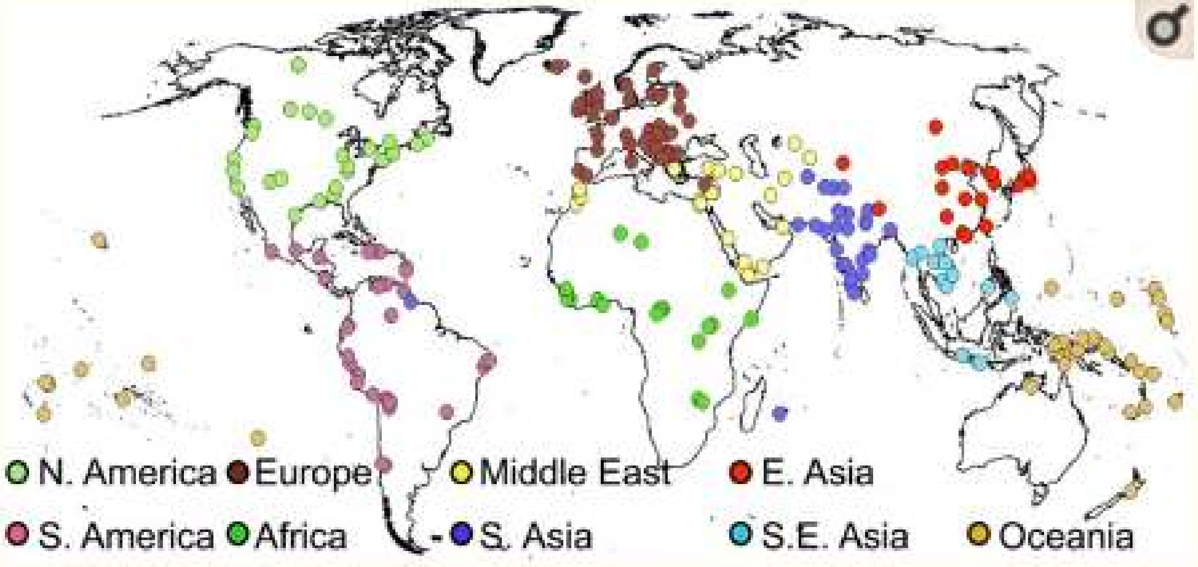
世界最早的乐器：
德国骨笛（35000年前）





Music is culturally universal

Statistical universals of human music
统计学上的人类音乐普遍规律



Open in a separate window

Fig. 1

The 304 recordings from the *Garland Encyclopedia of World Music* show a widespread geographic distribution. They are grouped into nine regions specified a priori by the *Encyclopedia*'s editors, as color-coded in the legend at bottom: North America (n = 33 recordings), Central/South America (39), Europe (40), Africa (21), the Middle East (35), South Asia (34), East Asia (34), Southeast Asia (14), and Oceania (54).

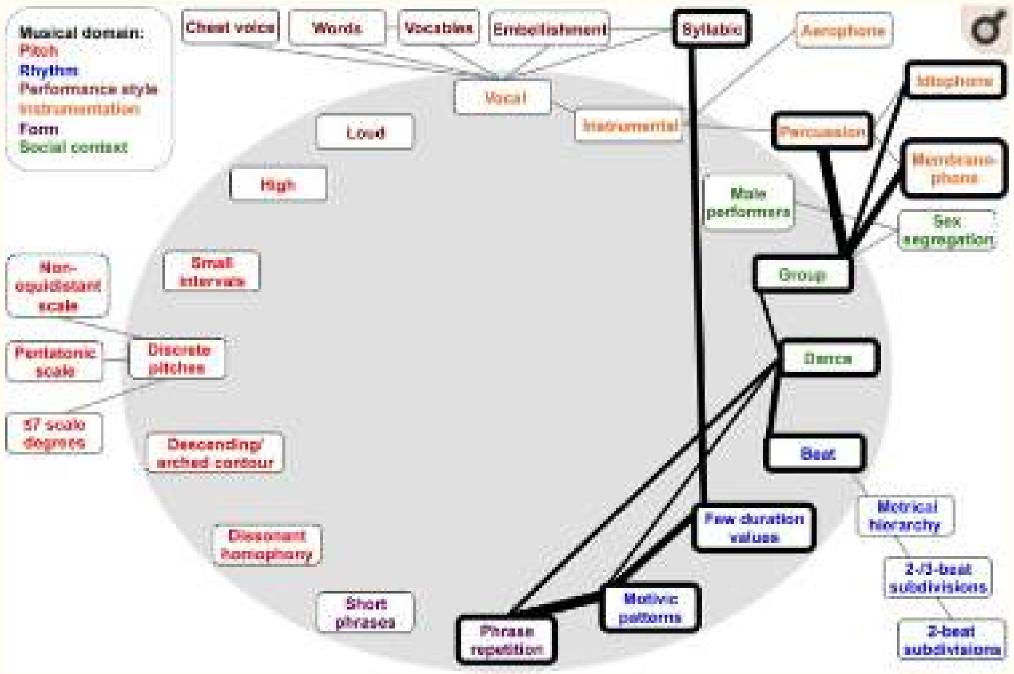


Fig. 3

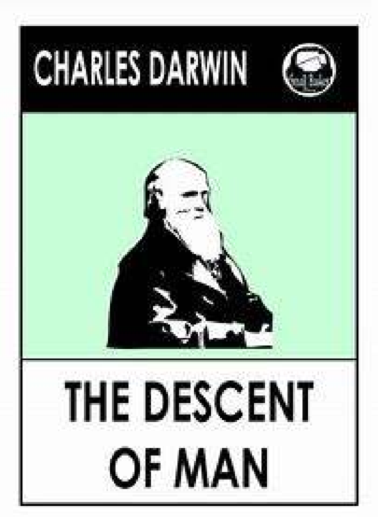
Universal relationships between the 32 musical features. Features are color-coded by musical domain (see legend at top left). The 16 connected features are distributed around the shaded oval, and the remaining 16 nested features outside the oval require one of the former features by definition. Dependent relationships implied by definition are highlighted using gray lines and were excluded from the analyses. Black lines indicate universal relationships that were significant after controlling for phylogenetic relationships and whose directions were consistent across all nine regions, with the width of each line proportional to the strength of the LR statistic from the phylogenetic coevolutionary analysis (see Table S1 for all pairwise LR values). Ten features (highlighted using bold boxes) formed a single interconnected network joined by one or more universal relationships.

Savage et al., 2015 PNAS

达尔文《物种起源》的观点

- 音乐非生活所必需“neither the enjoyment nor the capacity of producing musical notes are faculties of the least use to man in reference to his daily habits of life…” **Darwin, 1871**

- 求偶假说
- 语言前身假说



https://tse3-mm.cn.bing.net/th/id/OIP-C.9NTIRHbI-Vk_8-CFBR5jVAAAAA?pid=ImgDet&rs=1

Human musicality is a coevolved system for social bonding
人类音乐性是共同进化的社会联结系统

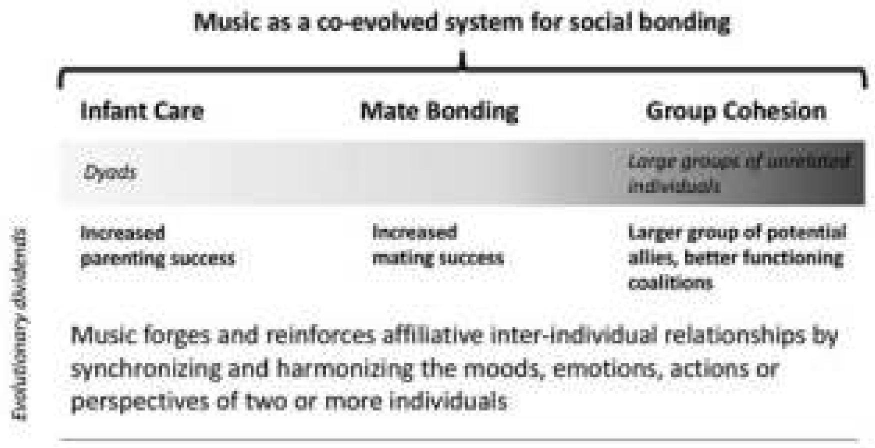


Figure 1. We propose that supposedly competing hypotheses for the evolution of human music, including mate bonding, infant care, and group cohesion (within both small coalitions and larger groups), are complementary sub-components of a broader social bonding function.

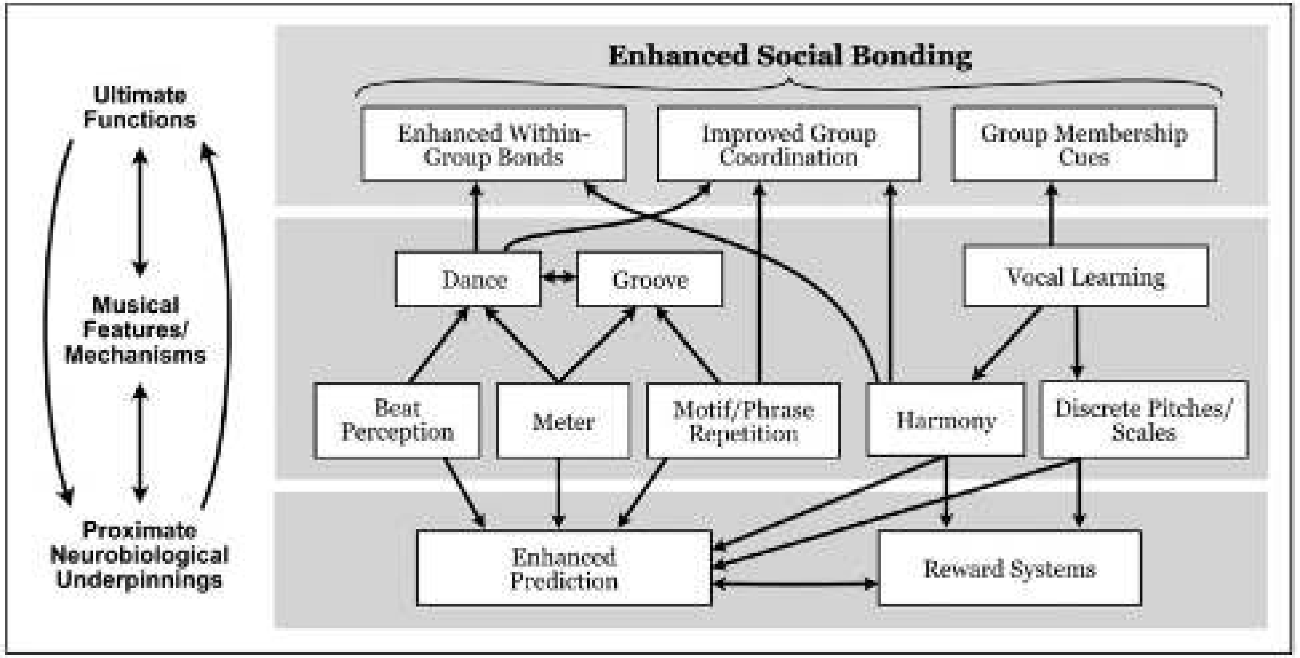
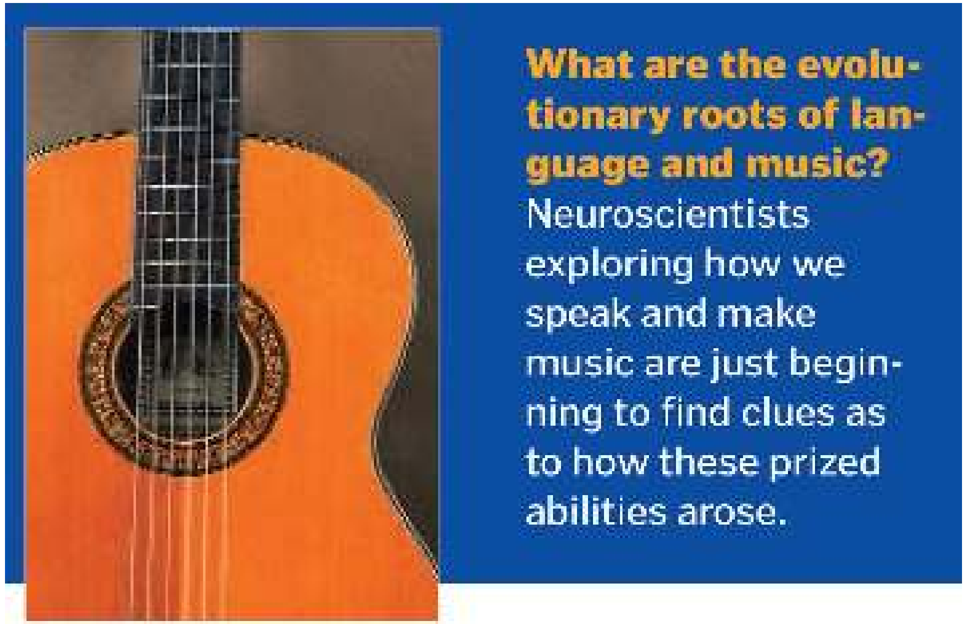


Figure 2. Proposed coevolutionary relationships among multiple musical features and mechanisms, indicating their contributions to ultimate functions by facilitating social bonding in multiple ways, their proximate neurobiological underpinnings in prediction and reward systems, and feedback loops among these different levels.

Savage et al., 2021 Behavioral Brain Sciences

Where did music come from?

- How did human beings evolve musical abilities?
- How long ago?



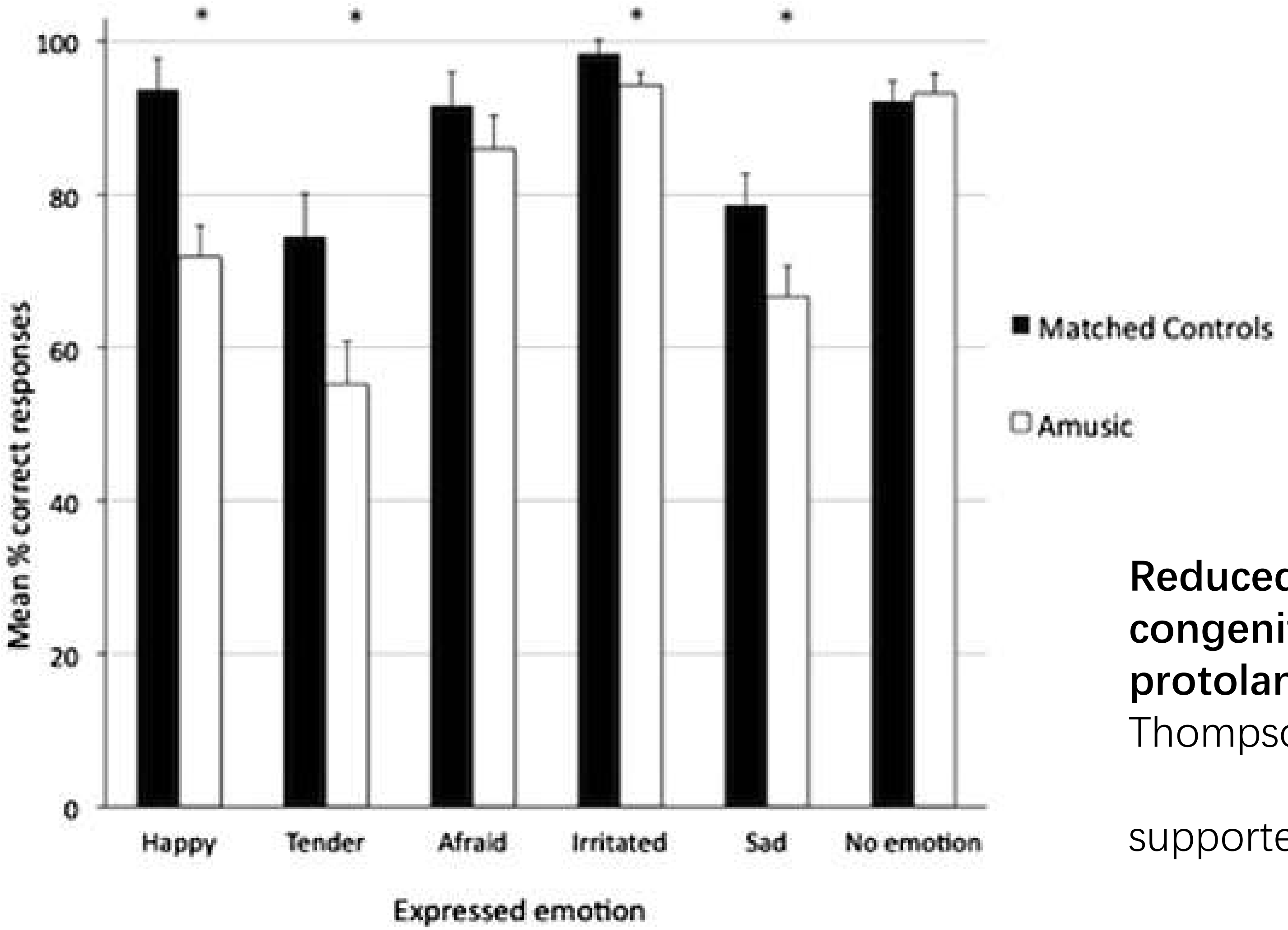
Science, 2005

114.语言和音乐演化的根源是什么?

Science, 2016

The percentage of correctly decoded prosodic stimuli intended to convey each of six emotional categories by amusic and control groups.

PNAS



William Forde Thompson et al. PNAS 2012;109:46:19027-19032

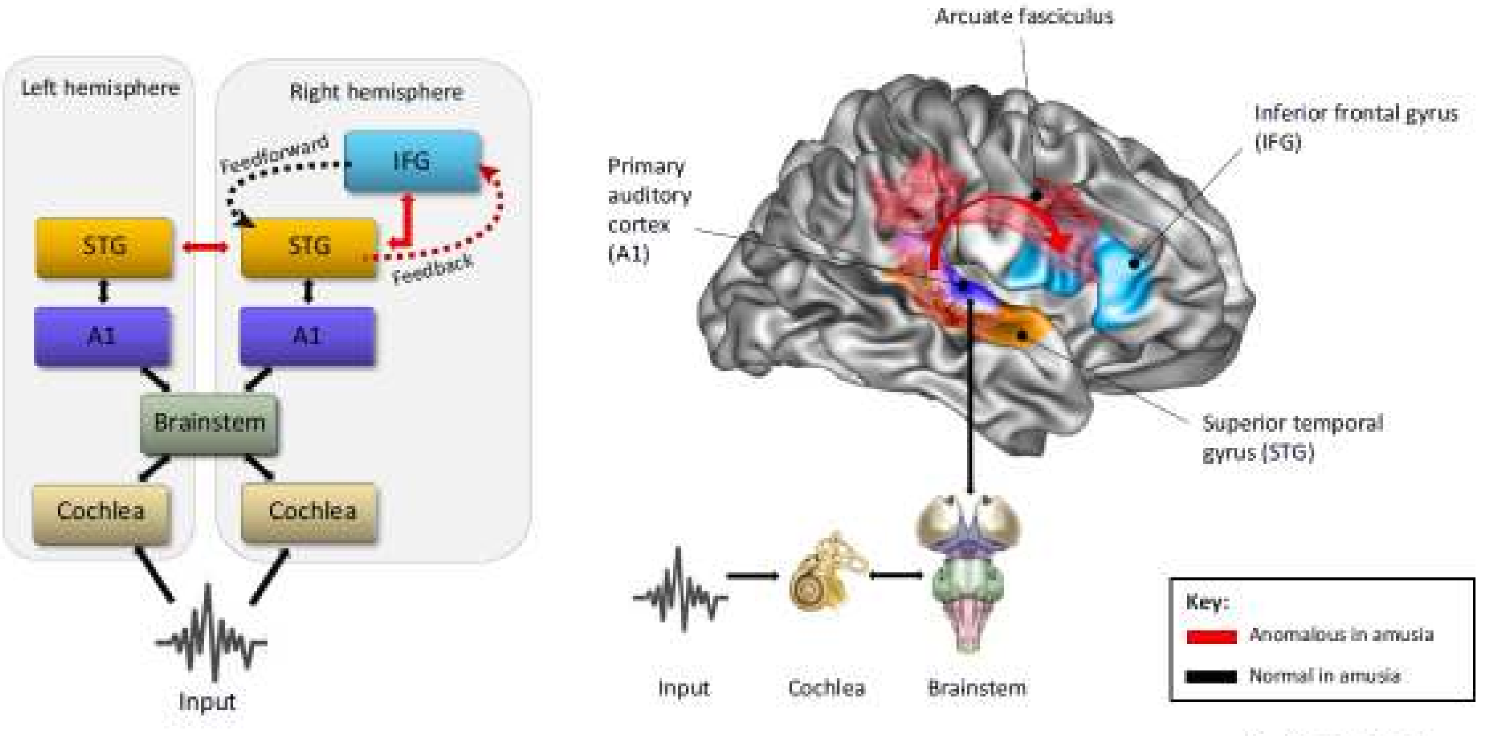
Reduced sensitivity to emotional prosody in congenital amusia rekindles the musical protolanguage hypothesis

Thompson et al., 2012 PNAS

supported musical protolanguage hypothesis

二、五音不全是怎么回事

“五音不全”即音乐学习障碍，是一种先天的遗传性音乐学习障碍，核心加工问题是音乐音高障碍。

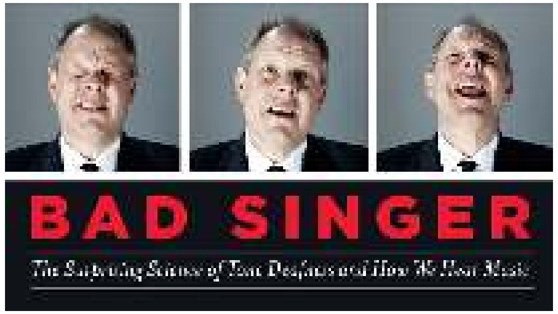


Trends in Cognitive Sciences

Figure 2. Anomalous Recurrent Processing in the Right Frontotemporal Network. Schematic (left panel) and anatomical representation (right panel) of the anomalies (in red) found in functional and structural connectivity between the right and left superior temporal gyrus (STG) and right inferior frontal gyrus (IFG) in the amusic brain as compared to the normal brain. Current evidence suggests that all other connections from the cochlea up to the STG, including the primary auditory cortex (A1), are normal. The proposed altered recurrent processing as a result of poor feedback control between the IFG and STG is represented by dashed lines.

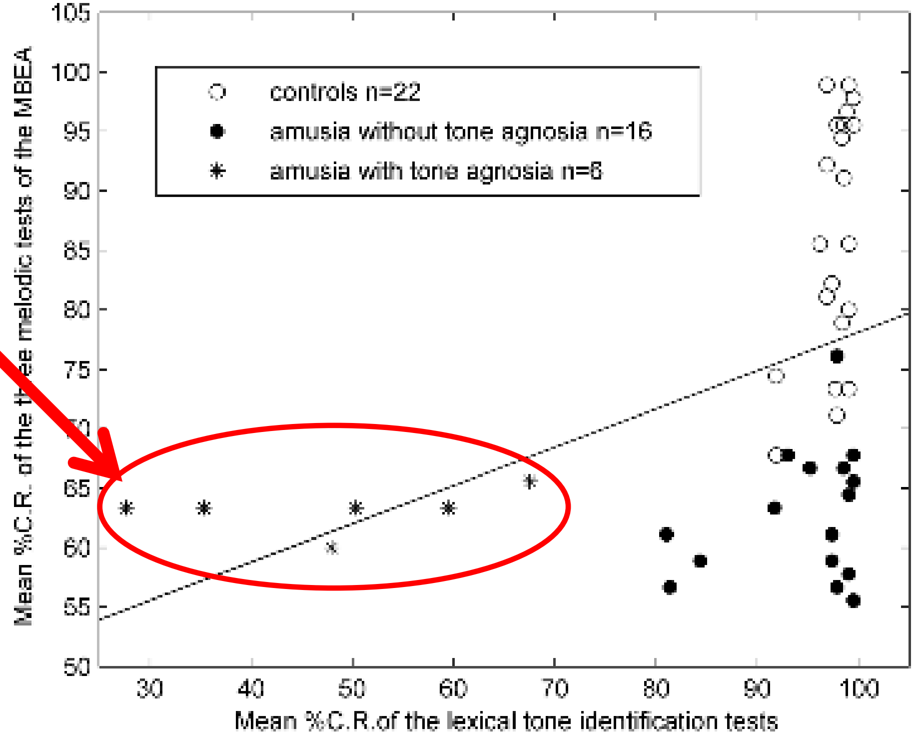
Peretz, 2016 TICS

Isabelle Peretz
University of Montreal

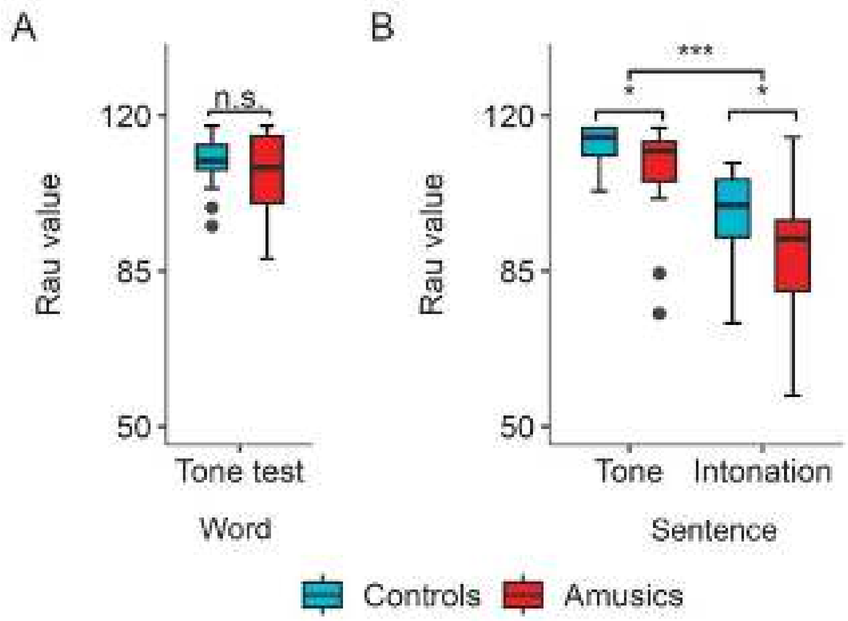


Tim Falconer, 2016

Will amusia affect speech tone processing?

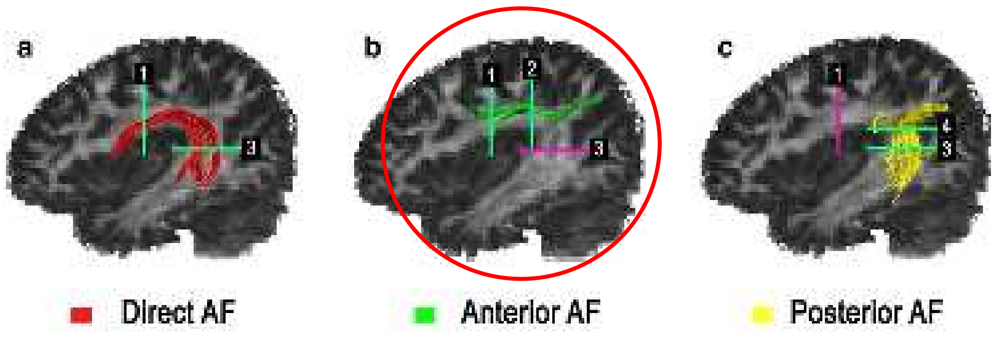


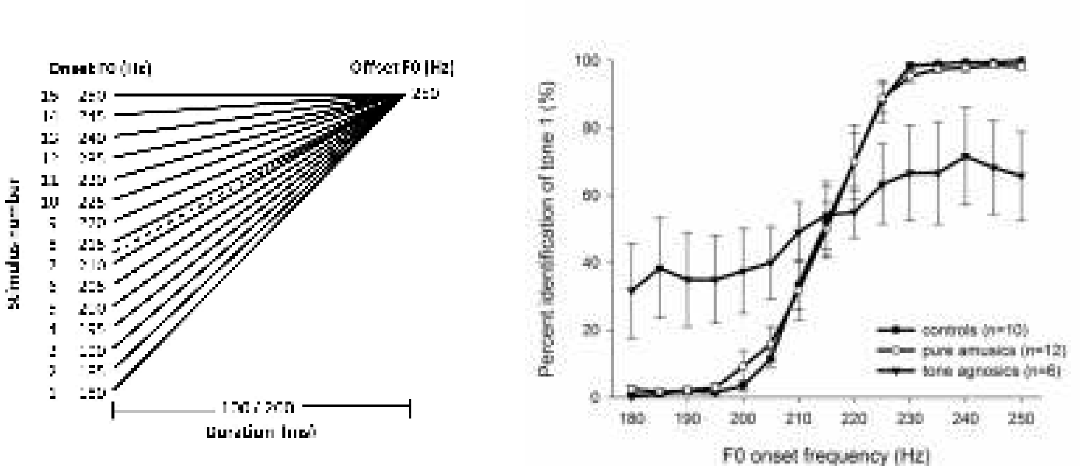
Nan et al (2010) ***Brain***



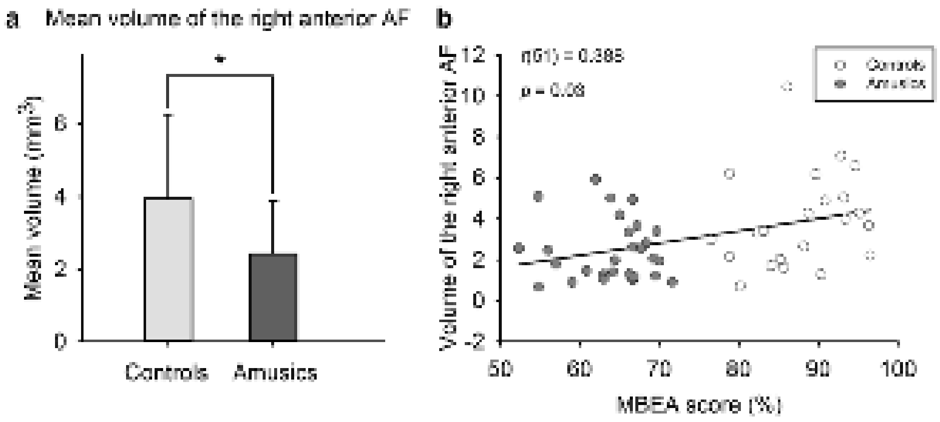
Tang et al (2024) ***JSLHR***

Neural correlates and cognitive mechanisms

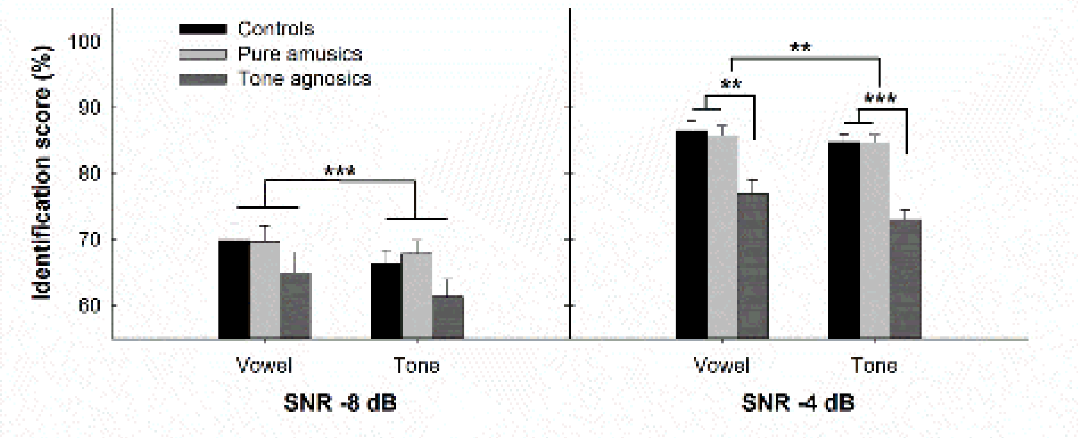




Huang et al., 2015 ***Frontiers in Psychology***

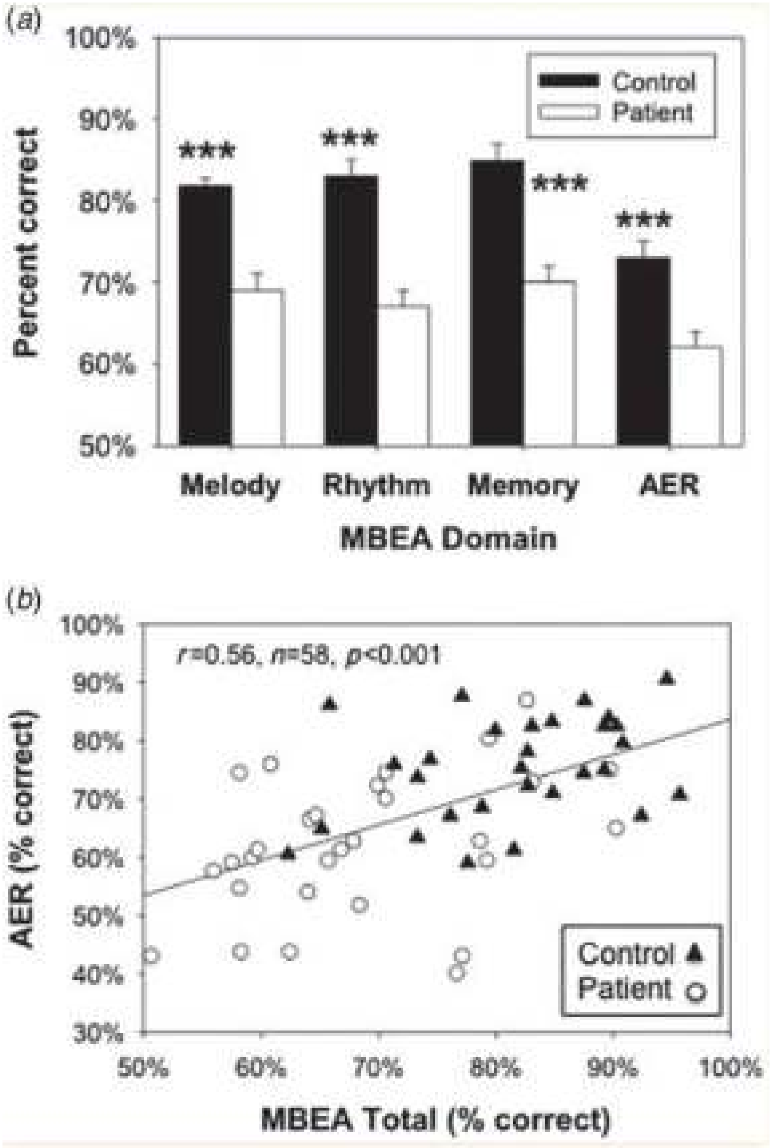


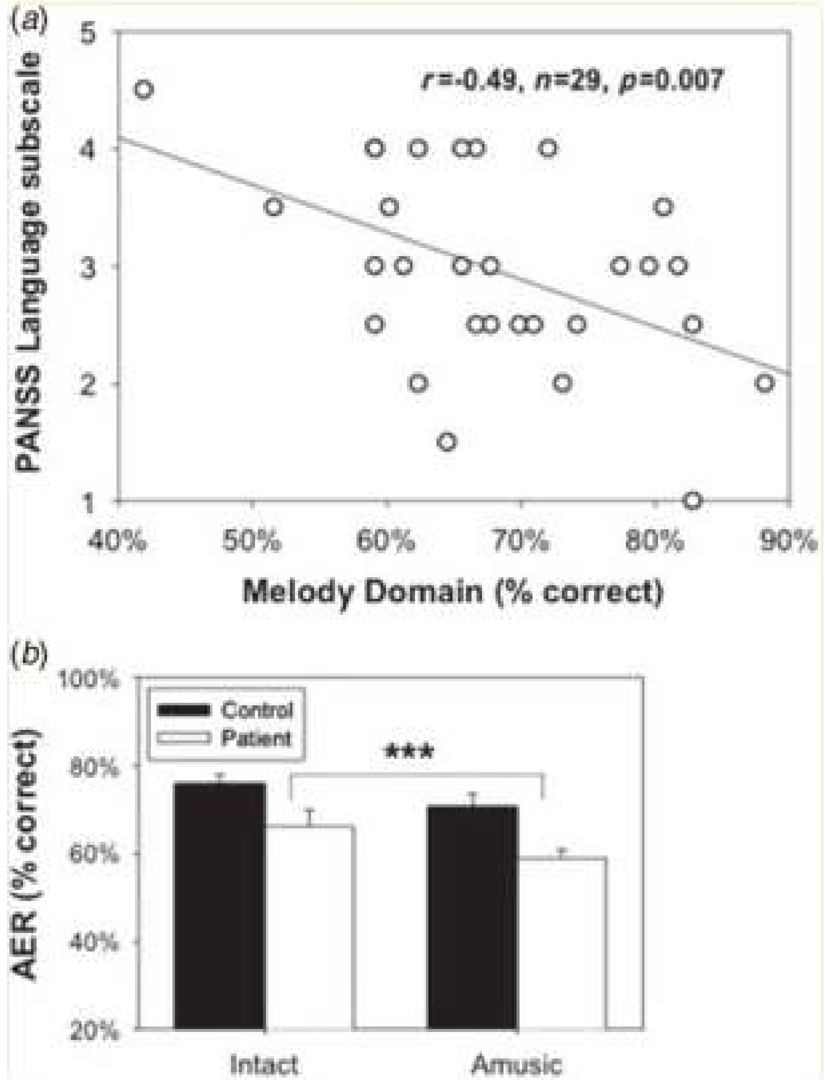
Chen et al., 2018 ***Brain Structure and Function***



Tang et al., 2018 ***Hearing Research***

Amusia and protolanguage impairments in schizophrenia



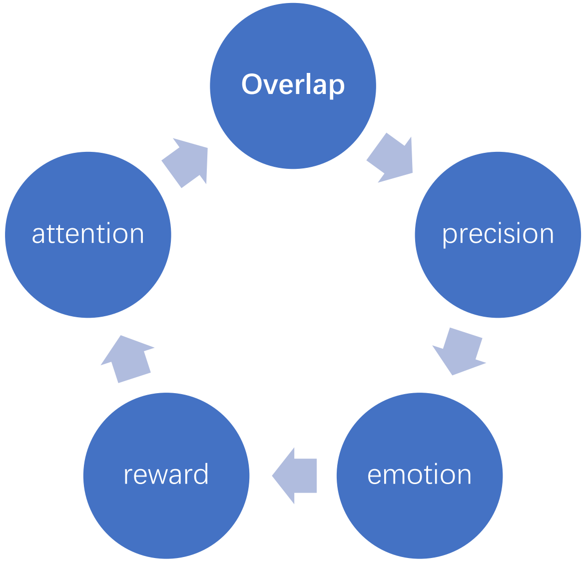


Kantrowitz et al., 2014 ***Psychol Med.***

三、音乐与语言的关系

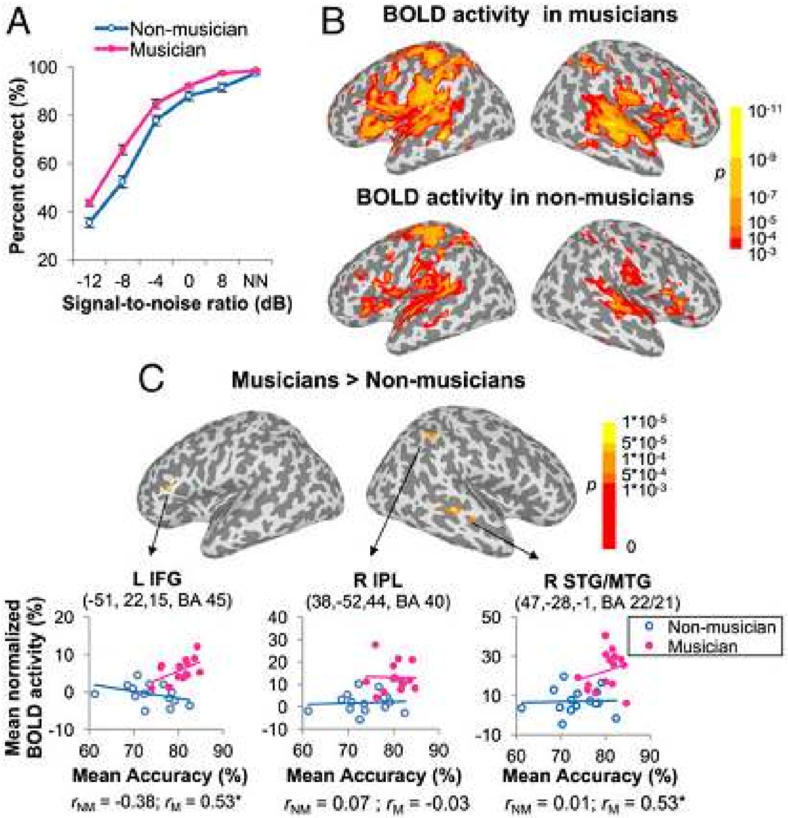
Aniruddh D. Patel,
Tufts University

音乐向语言迁移的OPERA模型



Patel, 2014

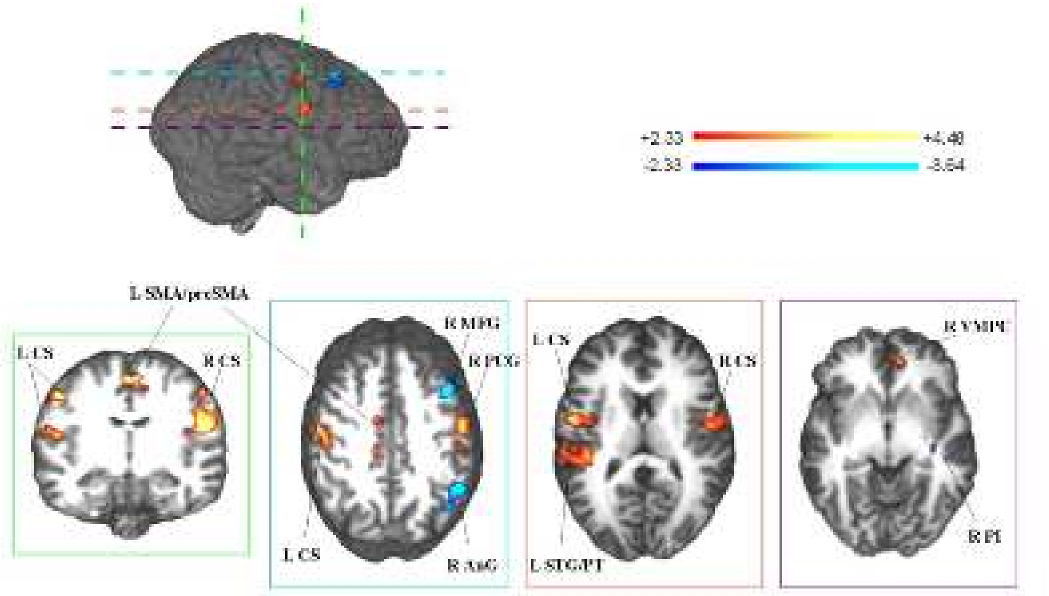
音乐经验促进噪音背景下语音识别



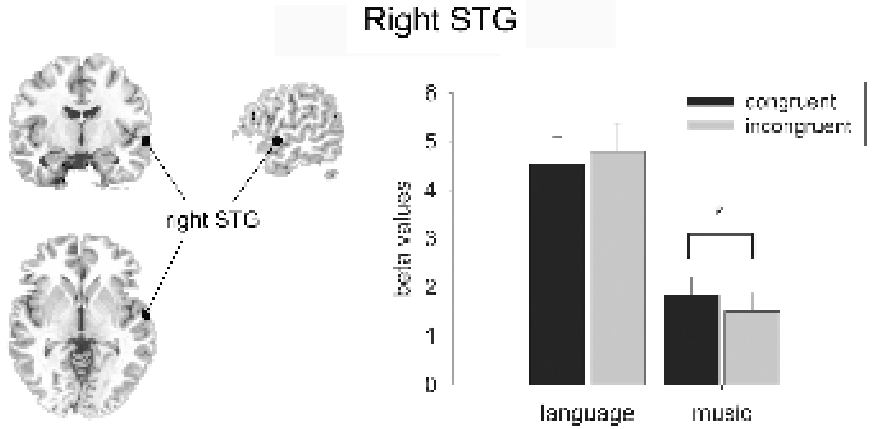
Du & Zatorre, 2017 PNAS

得到横断的相关结果，可以继续探索纵向追踪因果证据。

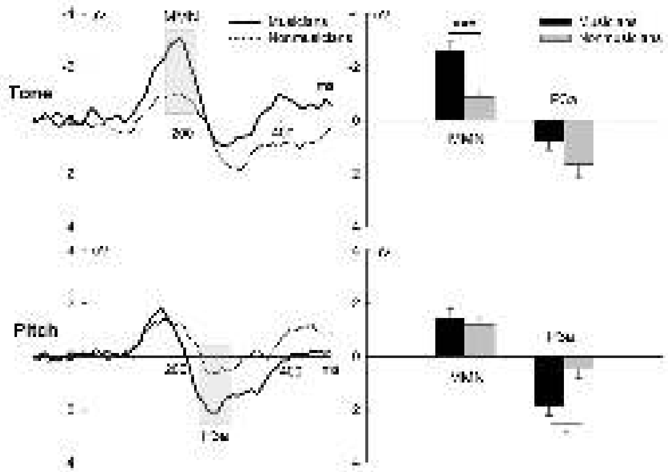
Pitch: Musicians’ advantage



Nan et al., 2008 ***Human Brain Mapping***

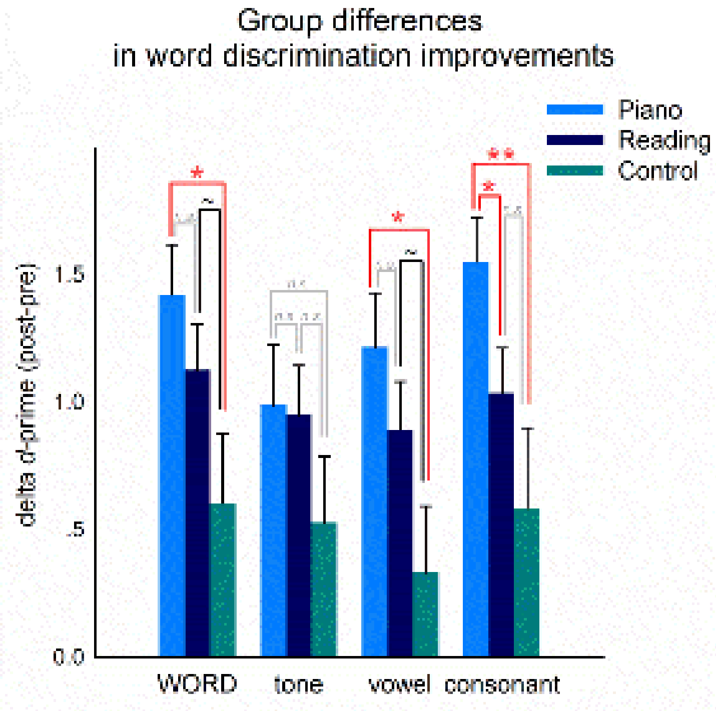


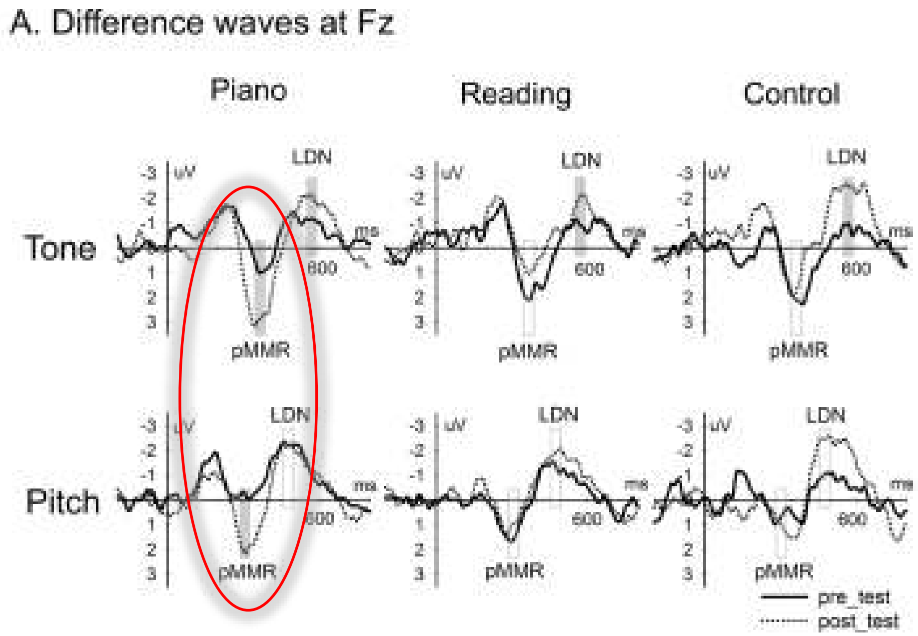
Nan & Friederici, 2013 ***Human Brain Mapping***

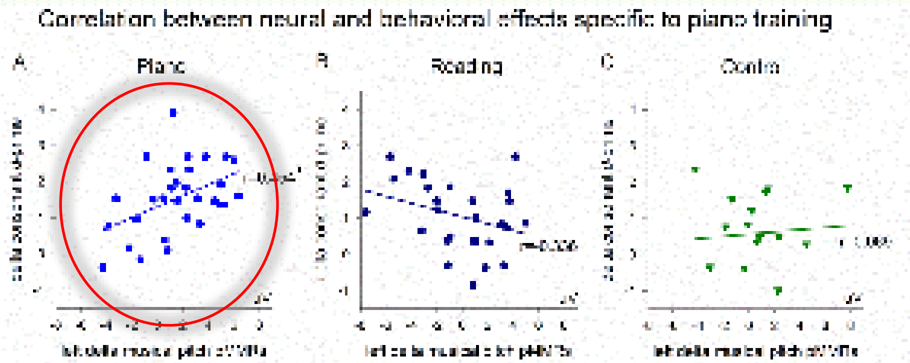


Tang et al., 2016 ***Neuropsychologia***

Musical training facilitates children's auditory word discrimination







-- Training effects in both tone and pitch

-- Improvements in consonant discrimination were correlated with neural enhancements in discriminating musical pitch

Nan et al., 2018 ***PNAS***

儿童小学阶段旋律与节奏的感知发展轨迹

旋律感知5-12岁持续发展

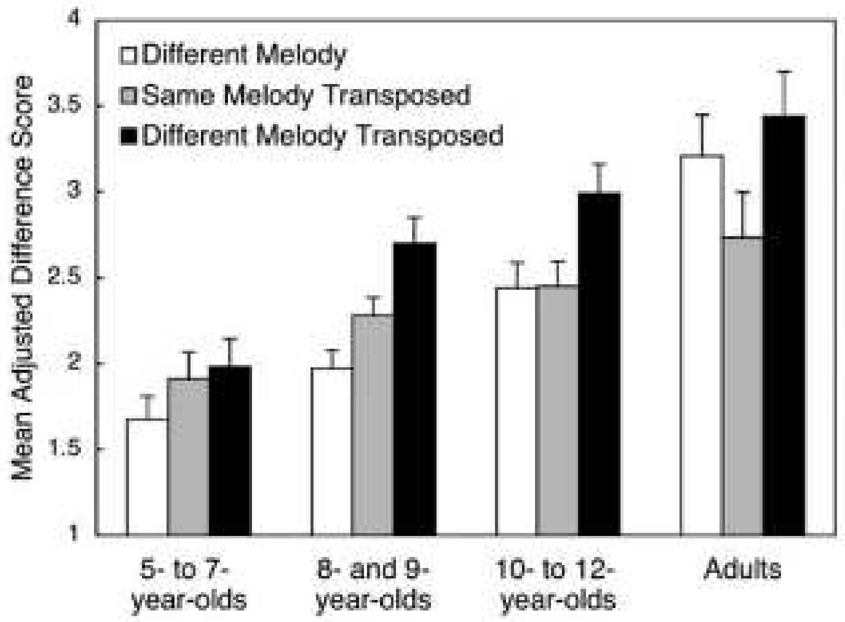
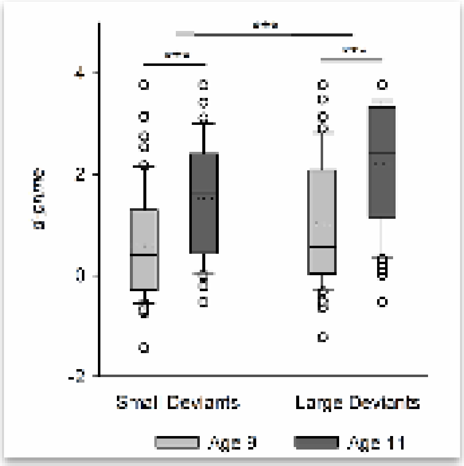
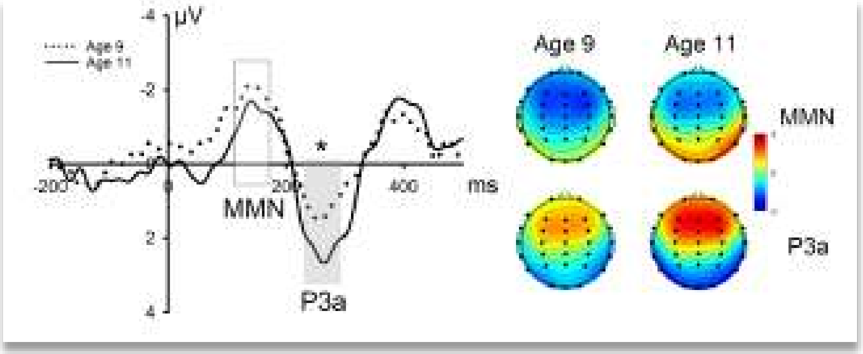


Figure 2. Means and standard errors for adjusted difference scores for each age group and for each type of melodic change. Scores were adjusted by dividing each listener's original scores by his or her score in the no-change condition. Higher scores correspond to greater perceived differences between melodies.

Stalinski & Schellenberg, 2010 Developmental Psychology

节奏感知9-11岁持续发展

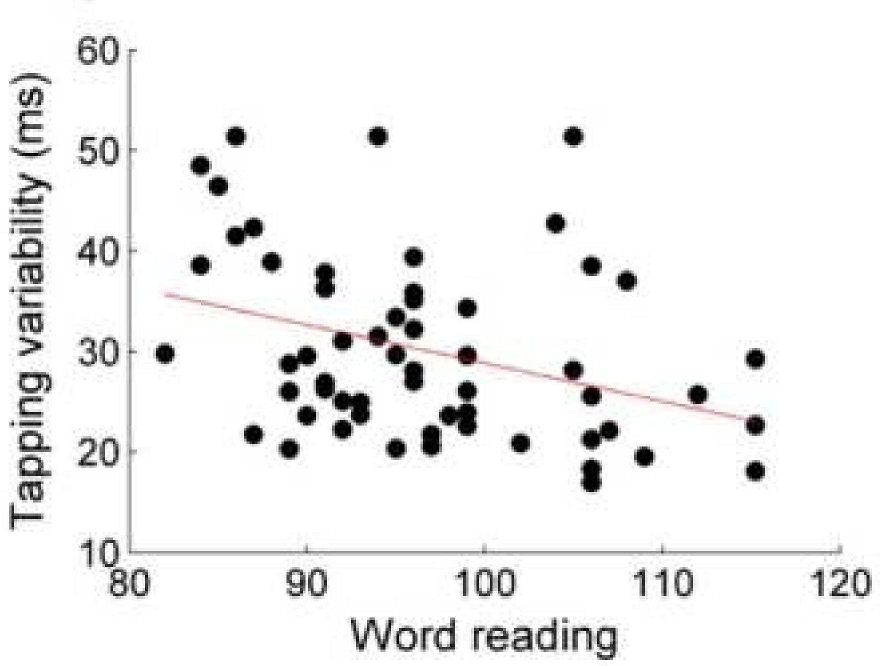




Sun et al., 2022 Brain and Language

音乐节奏加工 ⟷ 阅读相关技能

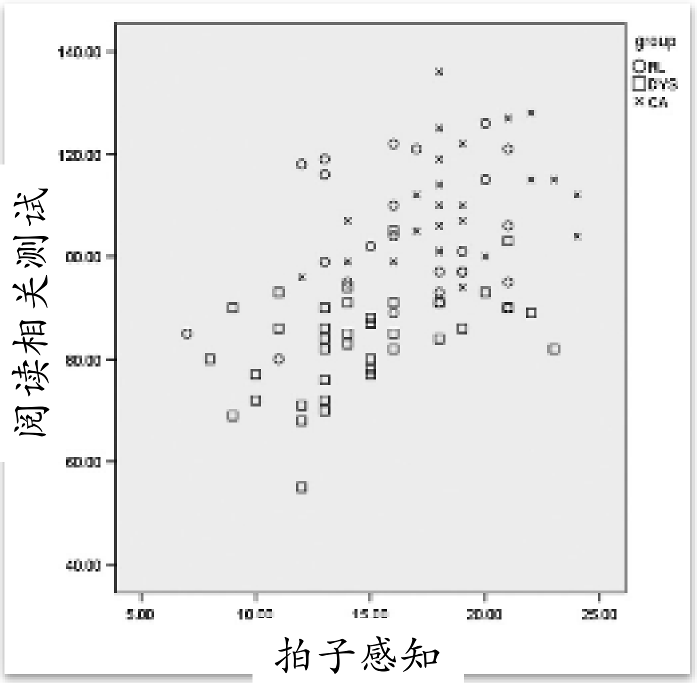
节奏能力与阅读能力相关



14-17岁高中生

(Tierney & Kraus., 2013)

拍子感知能力预测一年后的阅读能力



8-13岁学龄正常发展/阅读障碍儿童

(Goswami et al., 2013)

研究结果与讨论

音位删除

Step		Phoneme Deletion β	ΔR^2
Model 1			
1	MT	.261	.294**
	IQ	.304*	
	WM	.267*	
2	*d*-prime_s	.186	.029
2	*d*-prime_l	.266	.052
2	MMN_s	.148	.017
2	MMN_l	.087	.007
Model 2			
1	Autoregressor	.513***	.263***
2	*d*-prime_s	.163	.026
2	*d*-prime_l	.261*	.067*
2	MMN_s	.301*	.090*
2	MMN_l	.151	.023

声调辨别

Step		Tone Identification β	ΔR^2
Model 1			
1	MT	.267	.166*
	IQ	.219	
	WM	.111	
2	*d*-prime_s	.374**	.121**
2	*d*-prime_l	.251	.048
2	MMN_s	-.049	.002
2	MMN_l	.192	.032
Model 2			
1	Autoregressor	.544***	.295***
2	*d*-prime_s	.241	.053
2	*d*-prime_l	.203	.040
2	MMN_s	-.043	.002
2	MMN_l	.297*	.088*

阅读准确性（识字量）

Step		Reading Accuracy β	ΔR^2
Model 1			
1	IQ	.364*	.189*
	WM	.204	
2	TI	.099	.174*
	PD	.069	
	RAN	-.379**	
3	*d*-prime_s	-.065	.003
3	*d*-prime_l	-.026	.001
3	MMN_s	-.172	.021
3	MMN_l	.319*	.085*
Model 2			
1	Autoregressor	.815***	.665***
2	*d*-prime_s	.000	.000
2	*d*-prime_l	-.041	.002
2	MMN_s	.144	.020
2	MMN_l	.182*	.032*

阅读流畅性

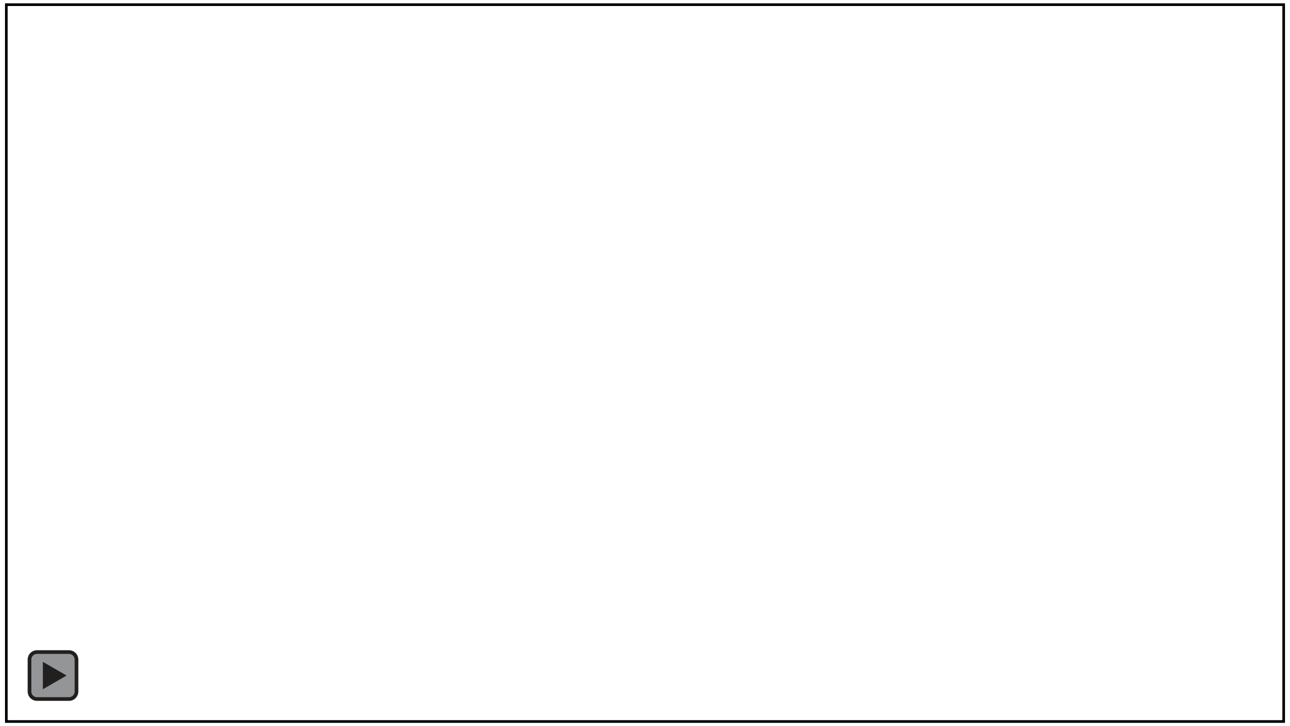
Step		Reading Fluency β	ΔR^2
Model 1			
1	IQ	.088	.053
	WM	.202	
2	TI	-.125	.284**
	PD	.251	
	RAN	-.507***	
3	*d*-prime_s	.015	.000
3	*d*-prime_l	.041	.001
3	MMN_s	-.097	.007
3	MMN_l	-.018	.000
Model 2			
1	Autoregressor	.663***	.440***
2	*d*-prime_s	-.032	.001
2	*d*-prime_l	-.002	.000
2	MMN_s	-.027	.001
2	MMN_l	.035	.001

- 节奏神经加工预测了语音加工表现及其发展
- 节奏神经加工预测了阅读表现（识字量）及其发展

Sun et al., 2022 ***Brain and Language***

现场实验，来听听音乐表达的情绪？

Sibelius - Finlandia op. 26
(Opening of the new Helsinki music hall)



Taylor Swift Adds ‘You’re on Your Own, Kid’ to Tokyo Surprise Section

四、我们为什么爱音乐

音乐不似食物，为人类生存所必需

是否也会激活奖赏系统?

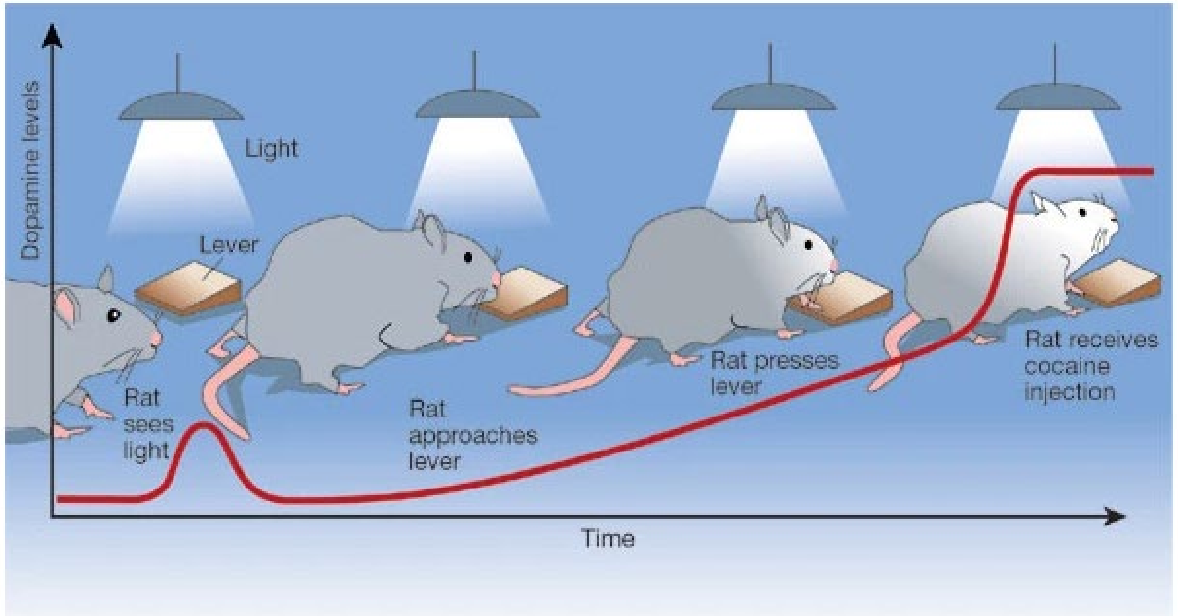
是否也伴随多巴胺的释放?

Lady Gaga's *Together at Home* Raised $128 Million for Covid-19 Relief

https://www.wired.com/story/lady-gaga-covid-19-coronavirus-relief/

Self, 2003 Nature; Phillips et al., 2003 Nature

Figure 1: The neurotransmitter dopamine both motivates reward-seeking behaviour and signals the receipt of a reward.



神经递质多巴胺

1. 驱动奖赏寻求行为
2. 标志奖赏获得

人脑的奖赏系统
The Reward System in human brain

钱　食物　配偶

眶额皮层

纹状体

杏仁核

丘脑

腹内侧前额叶

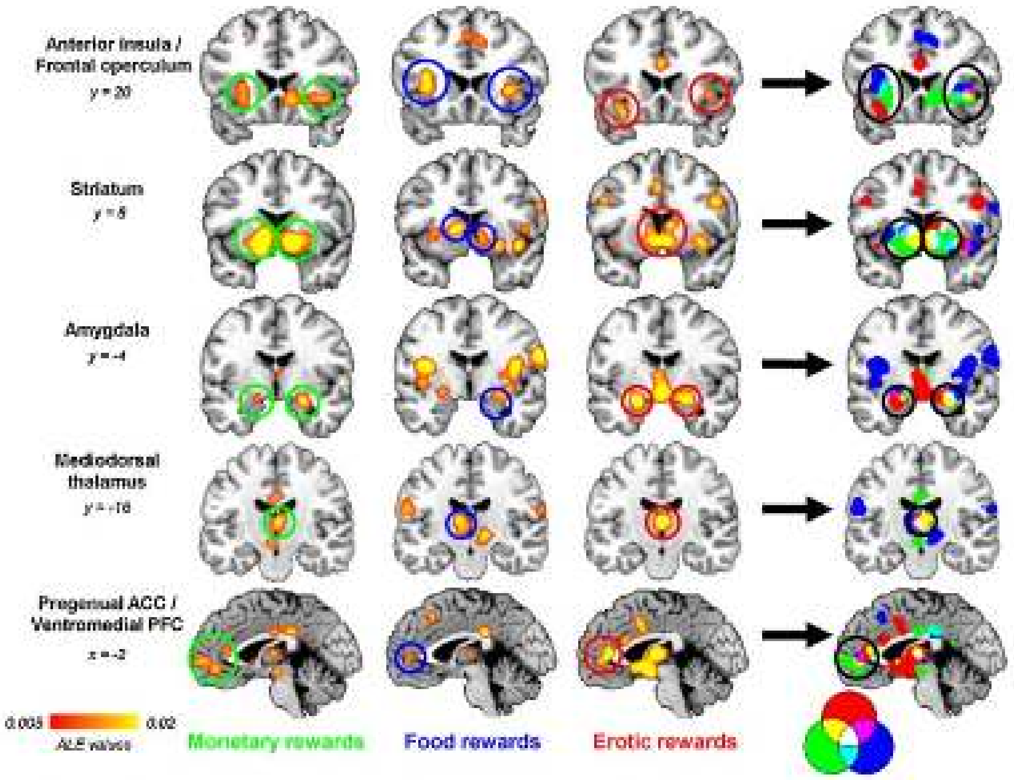


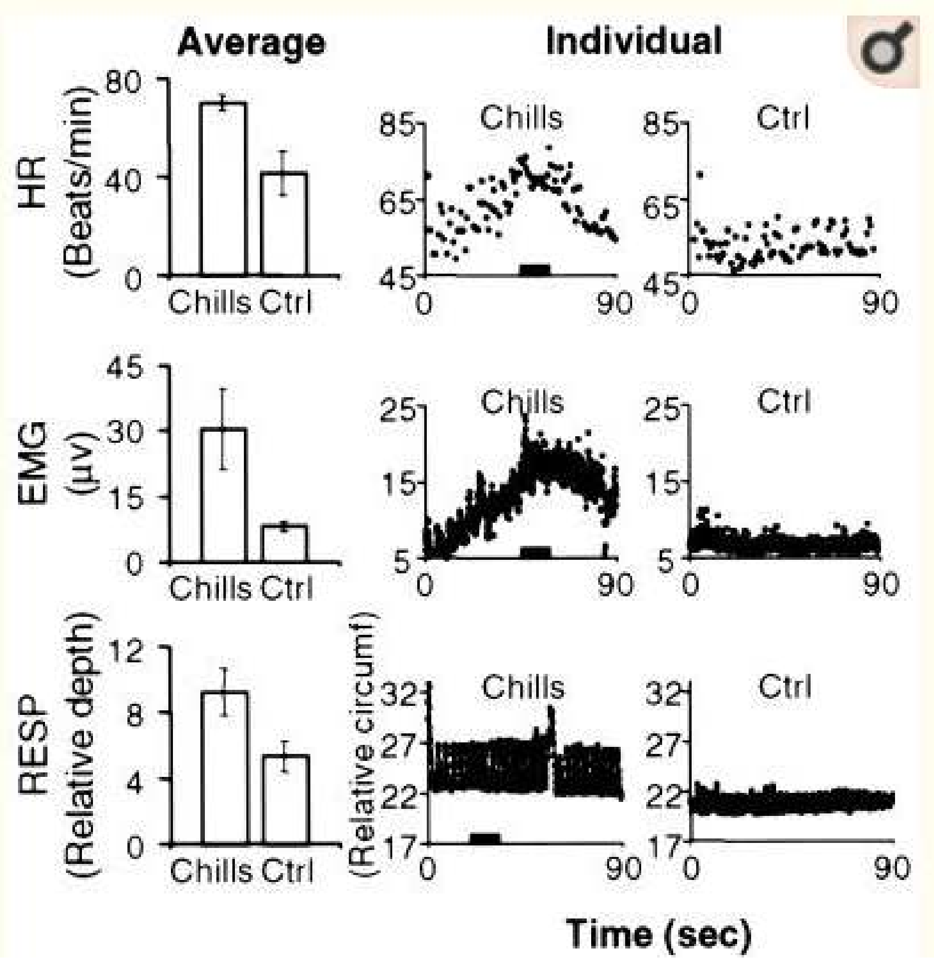
Fig. 1. "Common reward circuit" as defined by the overlap of ALE maps produced by monetary, food and erotic reward studies. The ALE maps in the three leftmost columns show the brain regions consistently and commonly activated by monetary, erotic and food reward outcomes. The colour scale indicates the magnitude of ALE values, i.e. the degree of consistency across studies. The maps on the right illustrate the overlap of activation clusters across rewards (green = monetary rewards, red = erotic rewards, blue = food rewards). The ALE maps are overlaid on the Colin brain provided with GingerALE ($p < 0.01$ FDR whole-brain corrected and cluster size > 600 mm^2). (For interpretation of references to colour in this figure legend, the reader is referred to the web version of this article.)

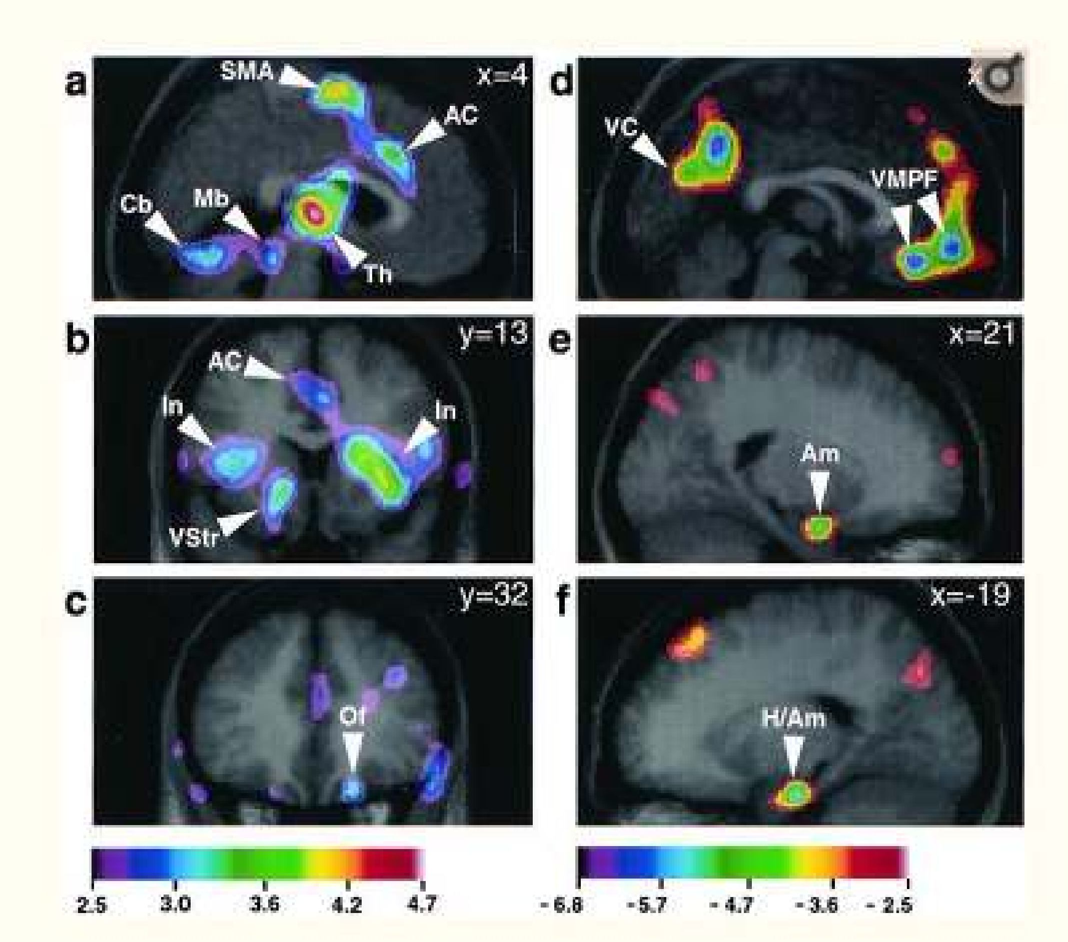
Sescousse et al., 2013

如何研究抽象的音乐?

Studying “chills” in music listening

Blood & Zatorre, 2001 PNAS





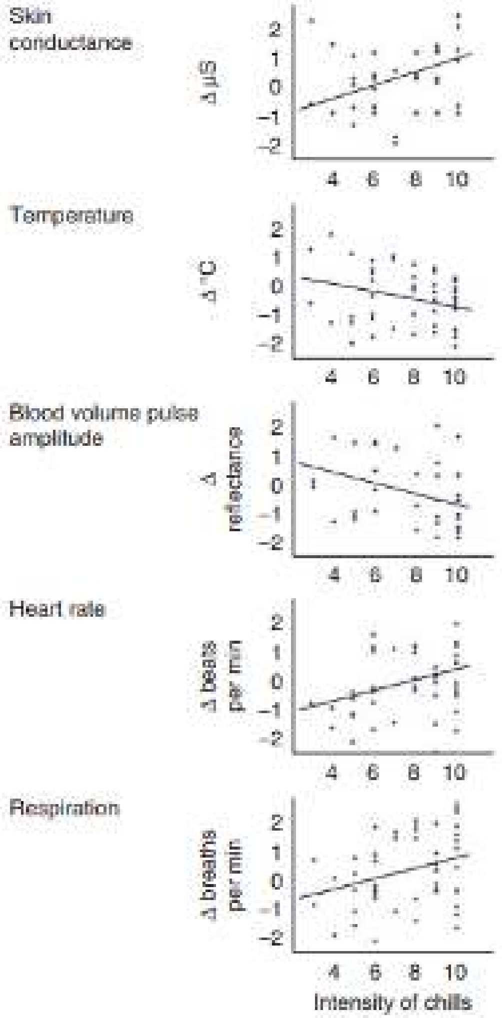
Positive correlations
With chills

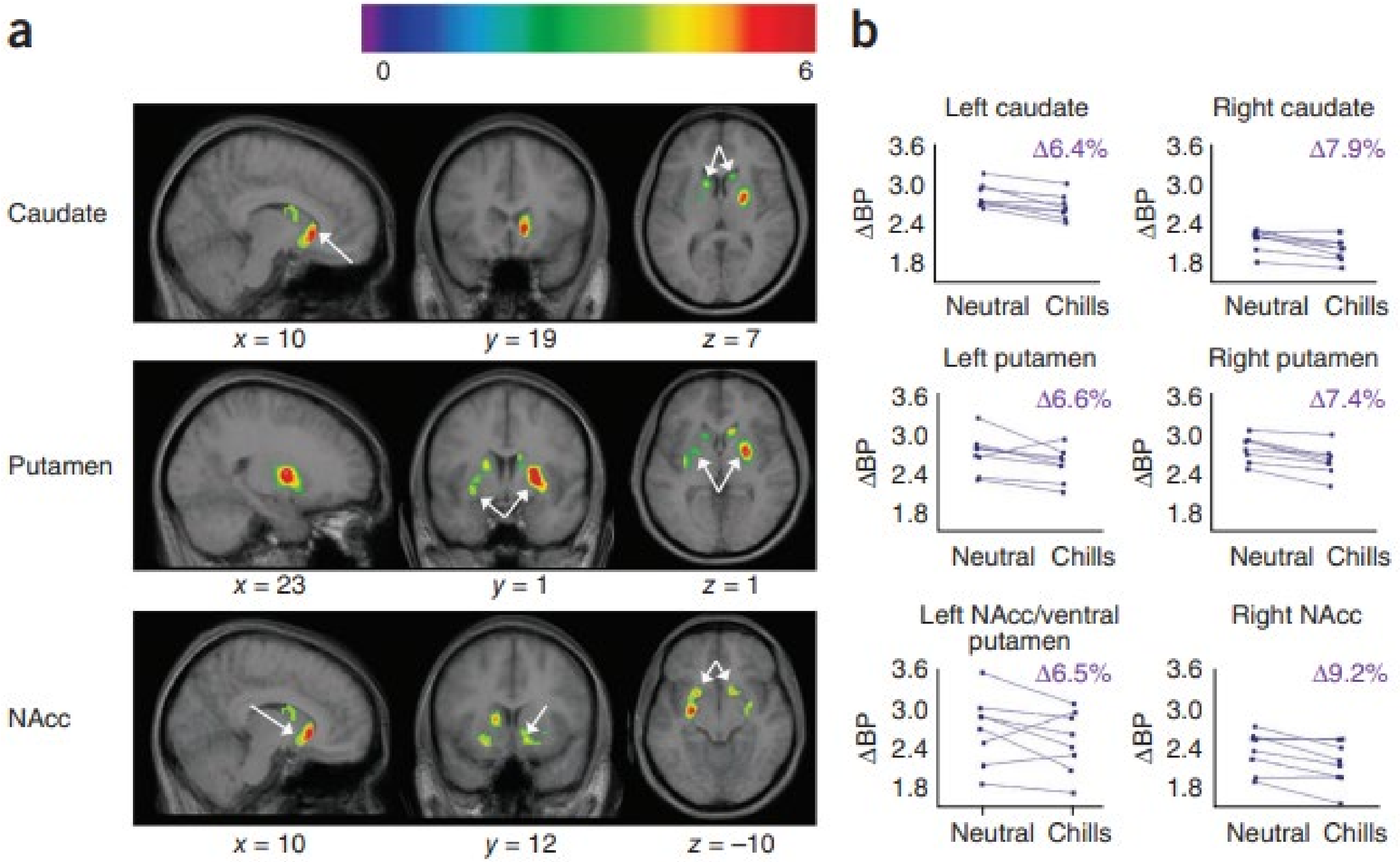
Negative correlations
With chills

是否也会有多巴胺的释放?
during “chills” in music listening

听喜欢的音乐会有多巴胺释放

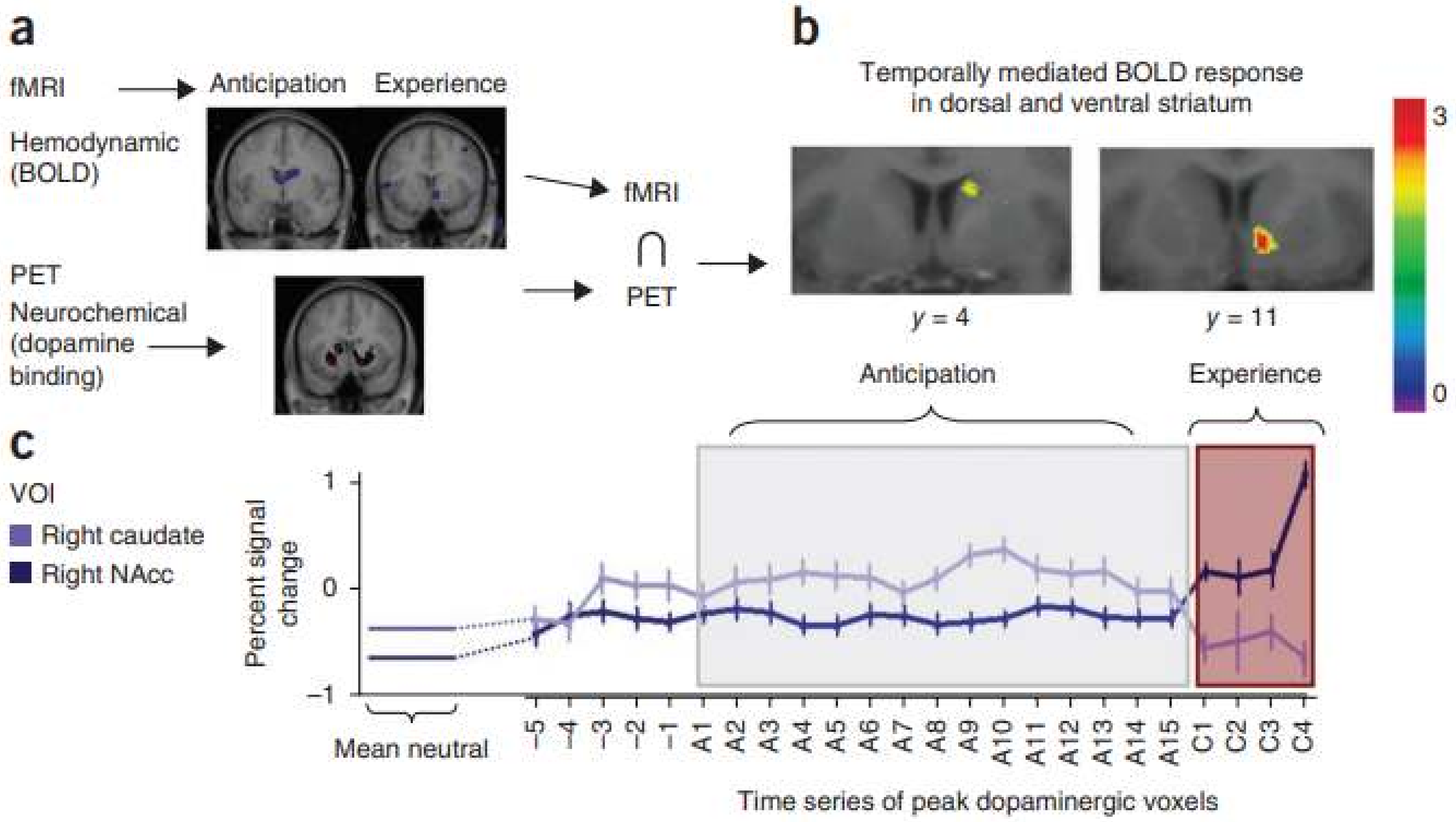
[11C]raclopride binding potential (BP)
= Availability of Dopamine D2 receptors
[11C] competes with endogenous dopamine





Salimpoor et al., 2011 Nature Neuroscience

多巴胺的释放也分为两个阶段：期待与奖赏获得



Salimpoor et al., 2011 Nature Neuroscience

Monetary amount as a proxy for music pleasure, when no chills present

Neural activity in Striatum associated with music reward

Fig. 2. Neural activity associated with reward value of music. (**A**) A whole-brain contrast revealed areas, including the dorsal and ventral striatum, that are active during the processing of desirable (bids > $0) as opposed to undesirable ($0 bids) music (table S2A). Z, plane of horizontal section (millimeters); t, value of t statistic; X, plane of vertical section (millimeters). (**B**) Among individuals who made sufficient bids in all categories (13), multiple linear regression allowed us to determine which purchasing-related regions (table S2B) corresponded to increasing reward value. Among the clusters from Fig. 1A, signal change in the right NAcc accounted for 33% of the variability in the amount spent, and the caudate accounted for an additional 10%; other regions did not contribute directly to reward value. Error bars indicate 1 SEM. (**C**) Average BOLD signal time course for the right NAcc and right caudate during the 30-s excerpts.

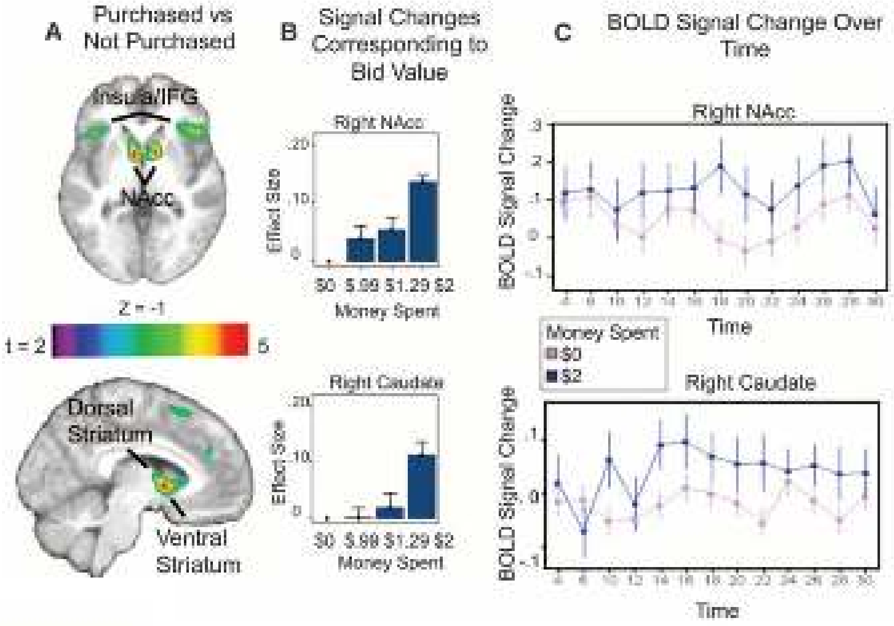
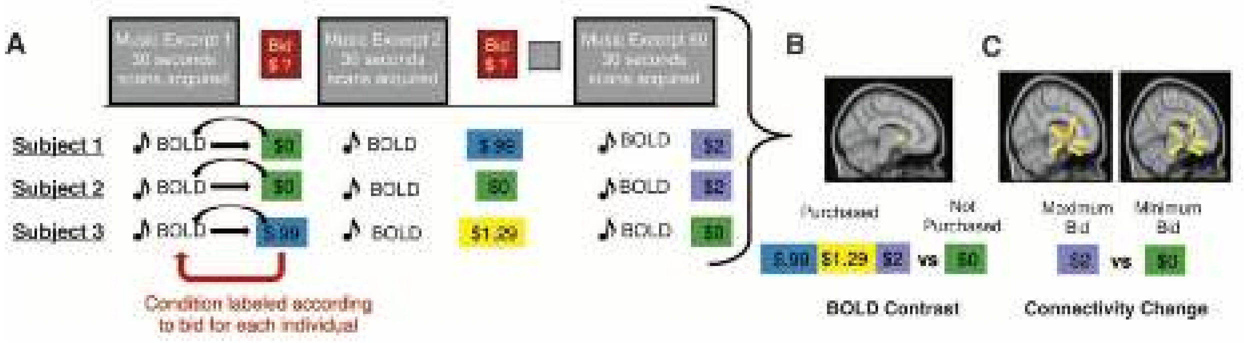


Fig. 1. Experimental paradigm. (**A**) Blood-oxygenation level–dependent (BOLD) activity was collected while participants listened to 60 30-s clips of new music (matched to their preferences by music-recommendation software, such as Pandora and Last.fm). Participants then placed bids with their own money that were used to categorize each excerpt according to desirability ($0, $0.99, $1.29, and $2) for the purposes of analysis. (**B**) Contrast analysis revealed regions associated with purchasing (Fig. 2A). (**C**) Multivariate connectivity methods allowed us to examine neural interactions associated with increased reward value of music (Fig. 3).



Salimpoor et al., 2013 Science

Music pleasure involves the auditory system and the reward system

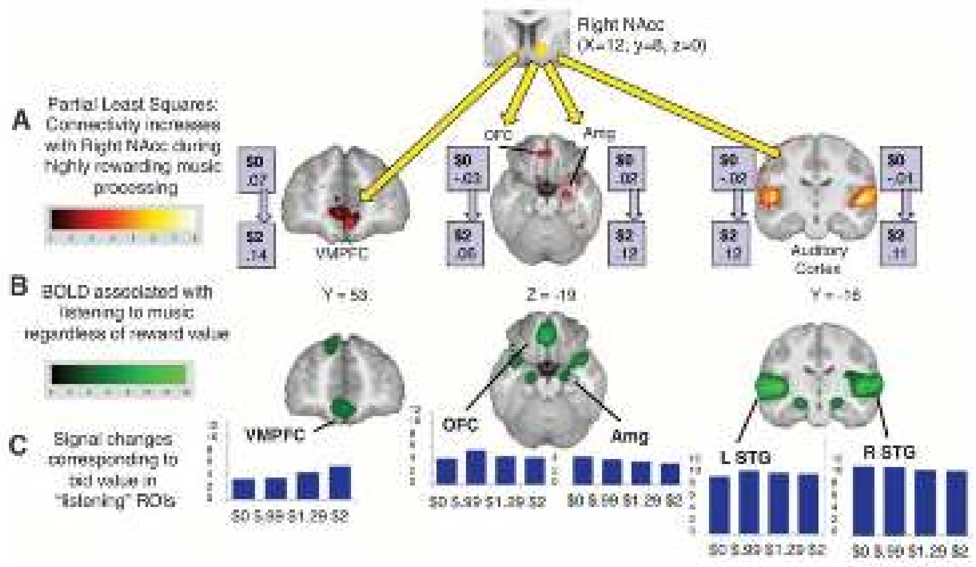
- the perceptual mechanism computes the relationships between sounds and generates expectancies based on those patterns
- "I just heard this sound, followed by that sound, therefore the next one should be X"

- the outcome of the prediction (sound X compared to the actual sound perceived) is then evaluated by the reward system
- "X is not as good as I expected, therefore it is not pleasurable, or X is surprising and better than expected therefore it is highly pleasurable"

Zatorre, 2018

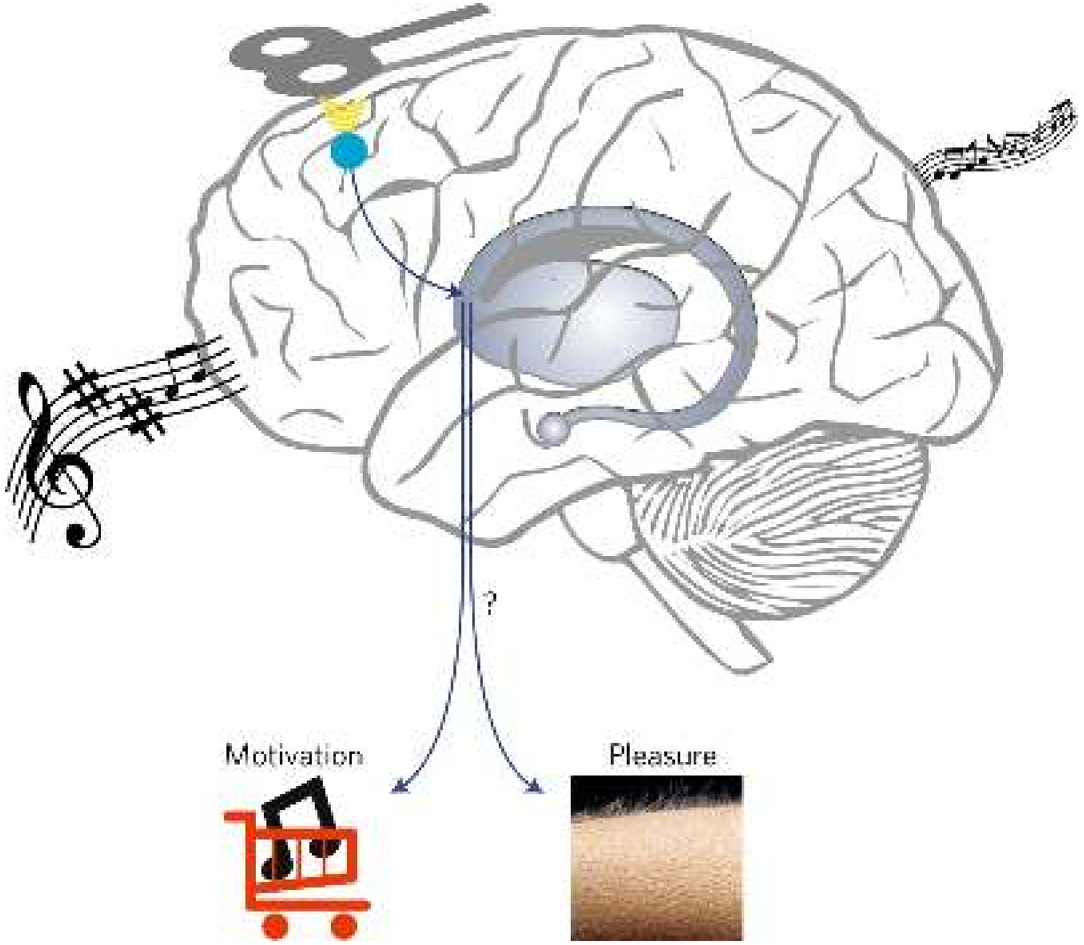
Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value

Fig. 3. Changes in NAcc functional connectivity associated with increasing desirability of music. (A) Partial least-squares analysis revealed robust increases in connectivity between the NAcc and other subcortical and cortical regions when individuals hear music they consider highly desirable, compared with music they do not want to hear again (table S3). Here, the boxes show changes in correlation as a function of amount bid between the NAcc and each region. A subset of these regions (A) overlap with areas that are recruited during music listening compared with rest (B). These areas show equally high activity during all music valuation conditions compared with rest (C), but their interactions with the NAcc increase as items become more desirable. Amg, amygdala; ROI, region of interest.



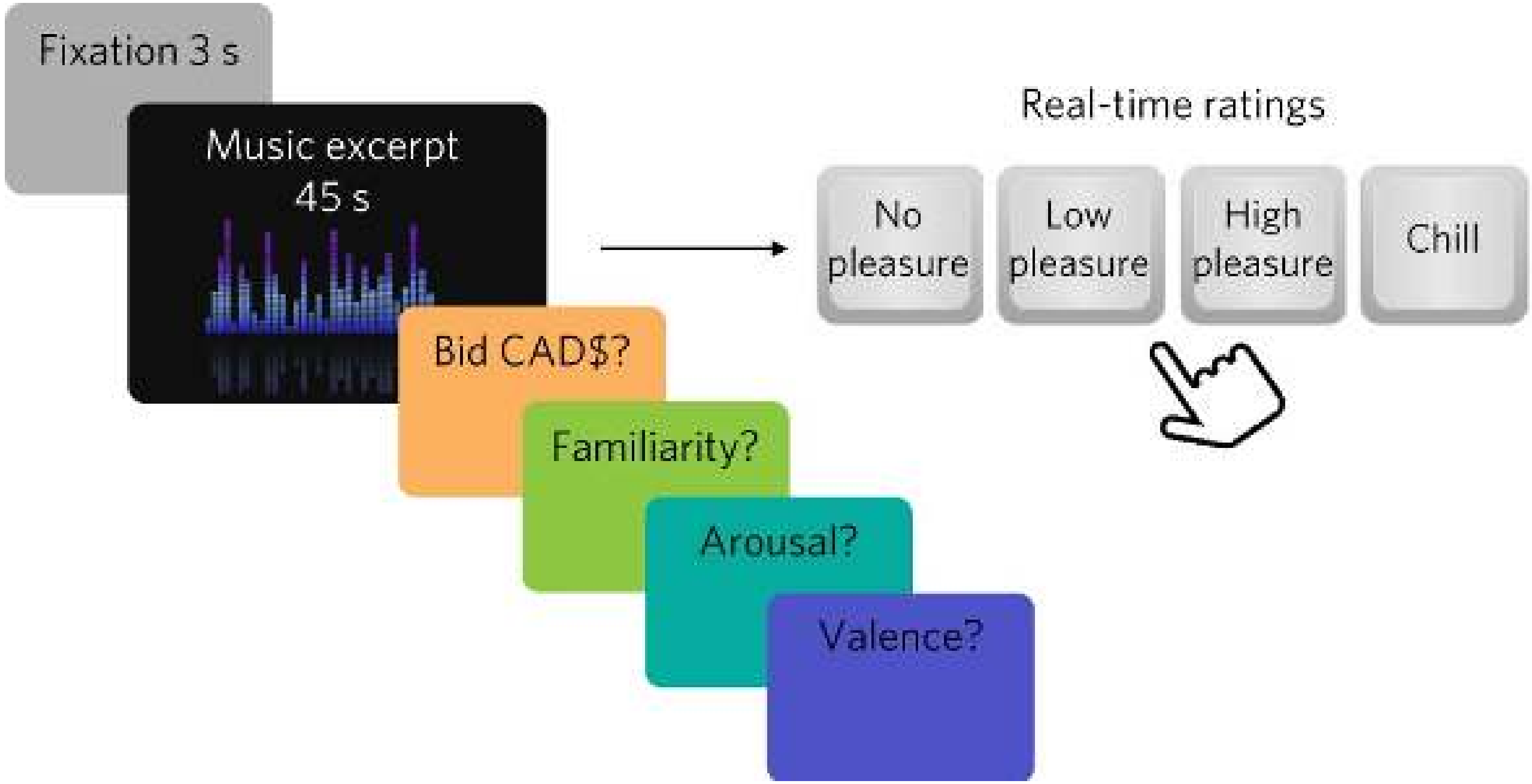
Salimpoor et al., 2013 Science

Is it causal? A TMS study



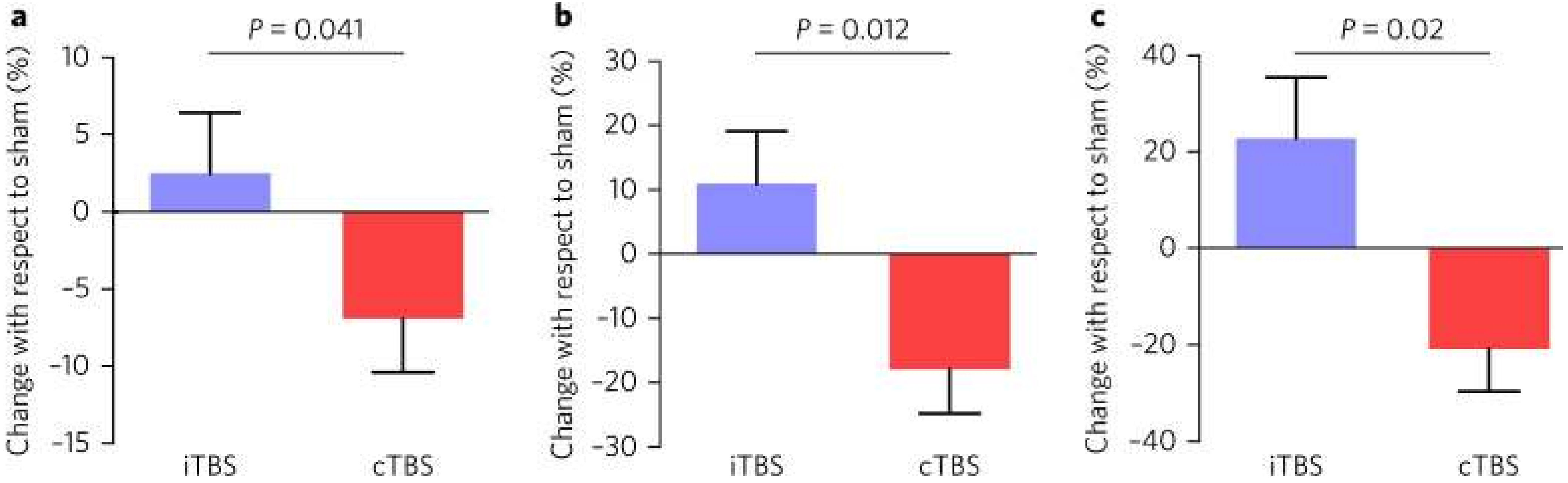
By using TMS over the left dorsolateral prefrontal cortex (blue dot), we aimed to induce changes in cortico-striatal function and study the causal role of this circuit in musical pleasure and motivation.
(Reward is not a unitary construct but involves at least two psychological components, specifically liking (the actual pleasure component) and wanting (the motivation to obtain a reward))

Mas-Herrero et al., 2017 Nature Human Behaivor



1) Rate in real-time the degree of pleasure they were experiencing by pressing the corresponding button;
the participants had to hold down the button as long as they were experiencing the corresponding degree of pleasure.
2) At the end of each excerpt, participants had to indicate the amount of money they were willing to pay
(only for the experimenter-selected excerpts).

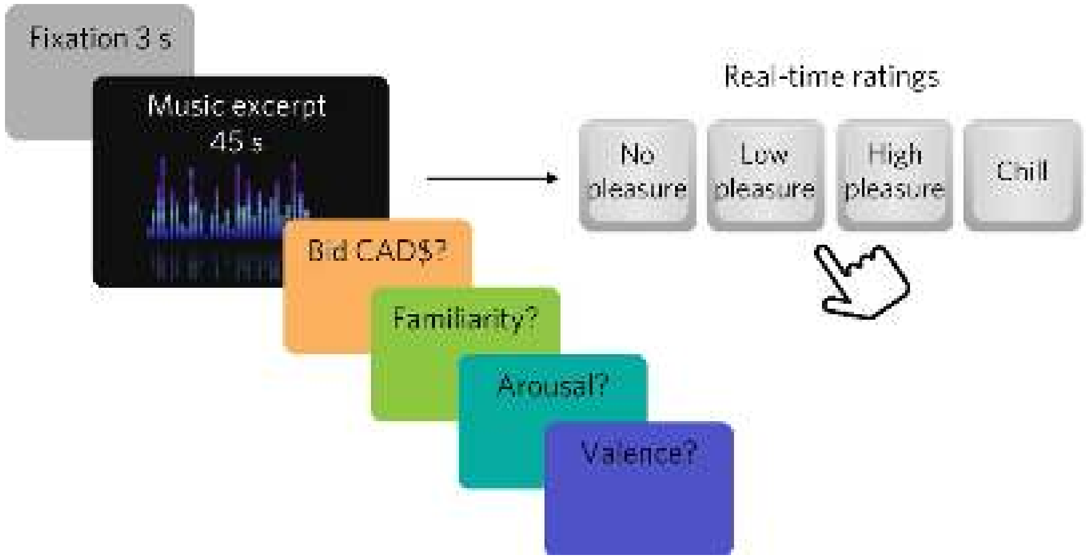
Results



a–**c**, The percentage change with respect to the sham condition following both iTBS and cTBS for liking rates (**a**), EDA during music listening (**b**) and the money spent to buy the music (**c**). Note that in all three variables, iTBS induces positive change while cTBS has the opposite effect. All percentages represented are the average change across the entire sample (*n* = 17). The black bars represent the standard error of the mean. Paired *t*-tests were used to compare both conditions. i:Intermittent (excitatory); c:Continuous (inhibitory)

Results (continued-1)

- Finally, there were no significant changes in familiarity, arousal or valence ratings for any of these measures (all *P* values > 0.15) as a function of the stimulation received.



they felt in response to each excerpt

At the end of each excerpt, participants had to indicate the amount of money they were willing to pay (only for the experimenter-selected excerpts), **the familiarity, the arousal and the emotional valence experienced by pressing the corresponding button on a keyboard**. Each question remained on the screen until participants' responded and after the last question, a new trial started.

PNAS

SEE COMMENTARY

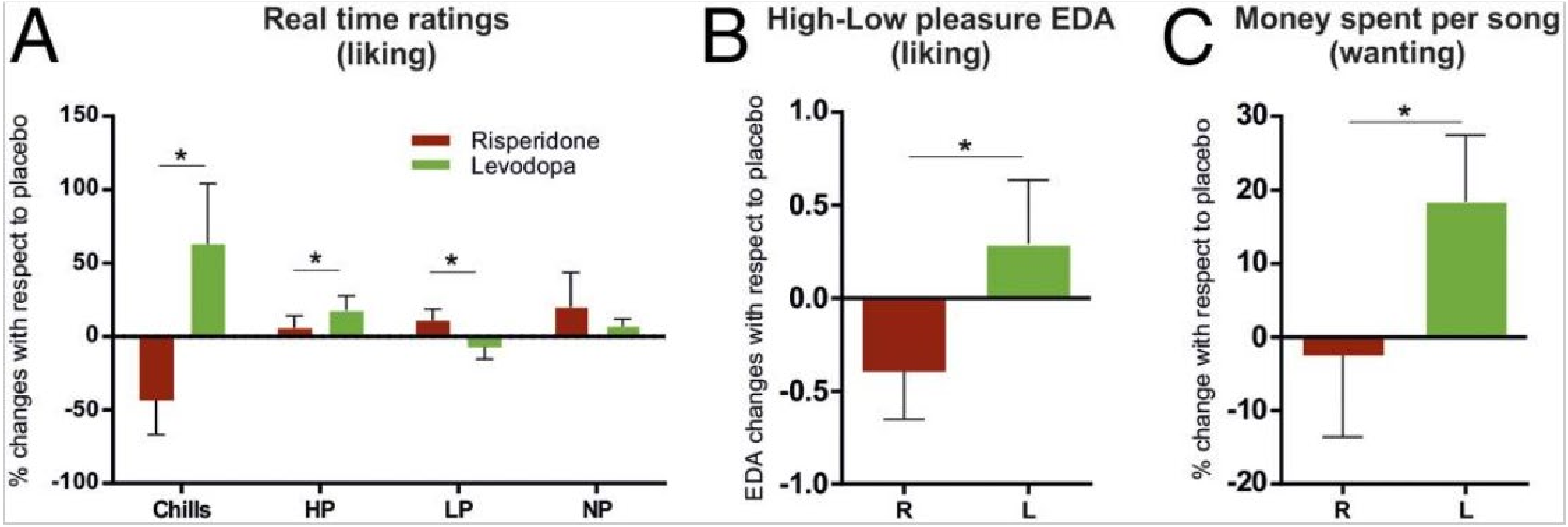
Dopamine modulates the reward experiences elicited by music

Laura Ferreri[a,b,c,1,2], Ernest Mas-Herrero[d,e,1], Robert J. Zatorre[d,e], Pablo Ripollés[f], Alba Gomez-Andres[a,b], Helena Alicart[a], Guillem Olivé[a,b], Josep Marco-Pallarés[a,b,g], Rosa M. Antonijoan[h,i], Marta Valle[i,j,3], Jordi Riba[k,3], and Antoni Rodriguez-Fornells[a,b,l,2,3]

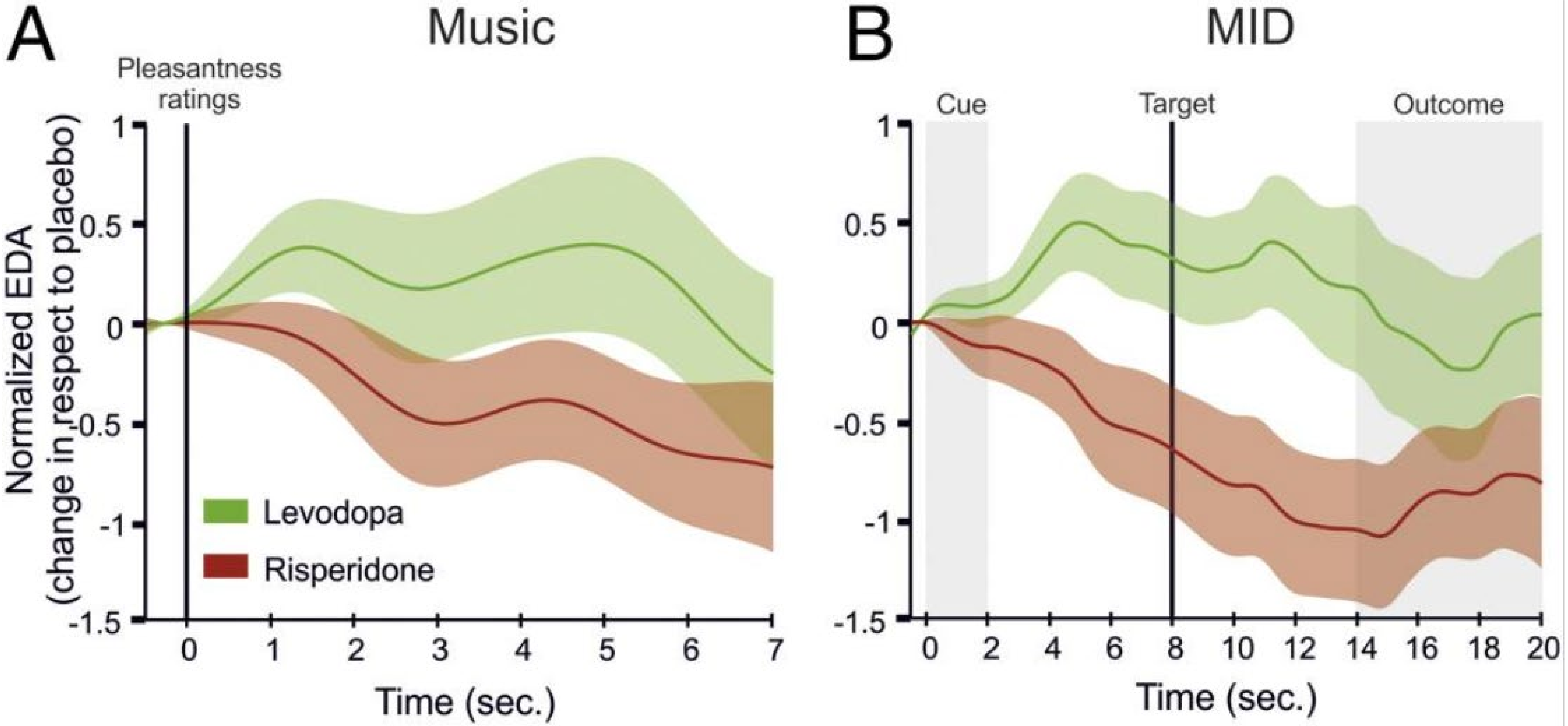
[a]Cognition and Brain Plasticity Unit, Bellvitge Biomedical Research Institute, L'Hospitalet de Llobregat, 08907 Barcelona, Spain; [b]Department of Cognition, Development and Education Psychology, University of Barcelona, 08035 Barcelona, Spain; [c]Laboratoire d'Etude des Mécanismes Cognitifs, Université Lumière Lyon 2, 69676 Lyon, France; [d]Montreal Neurological Institute, McGill University, Montreal, QC H3A 2B4, Canada; [e]International Laboratory for Brain, Music and Sound Research, Montreal, QC H2V 4P3, Canada; [f]Department of Psychology, New York University, New York, NY 10003; [g]Institute of Neuroscience, University of Barcelona, 08035 Barcelona, Spain; [h]Centre d'Investigació de Medicaments, Servei de Farmacologia Clínica, Hospital de la Santa Creu i Sant Pau, 08041 Barcelona, Spain; [i]Departament de Farmacologia i Terapèutica, Universitat Autònoma de Barcelona, 08193 Barcelona, Spain; [j]Pharmacokinetic/Pharmacodynamic Modeling and Simulation, Sant Pau Institut of Biomedical Research, 08041 Barcelona, Spain; [k]Department of Neuropsychology and Psychopharmacology, Maastricht University, 6229 Maastricht, The Netherlands; and [l]Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Edited by Solomon H. Snyder, The Johns Hopkins University School of Medicine, Baltimore, MD, and approved December 14, 2018 (received for review July 12, 2018)

Results: reported chills and pleasure



Results (continued-1): EDA

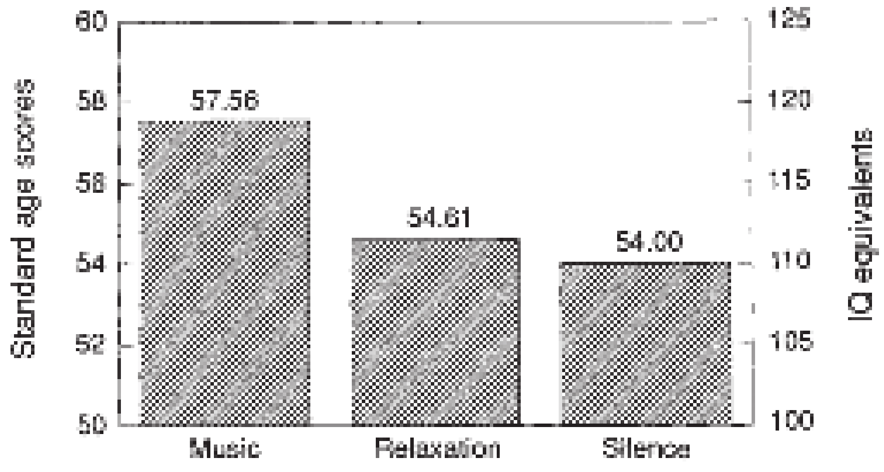


Results (continued-2): participants' aesthetic judgments provided after each song

- from 1 = no pleasantness to 5 = intense pleasantness
- computed percent of change following risperidone or levodopa administration with respect to placebo
- The analysis revealed a marginal difference between drugs: individuals tend to report higher liking rates following levodopa than risperidone ($Z = -1.947$, $P = 0.052$, Wilcoxon signed-rank test).
- No significant changes were observed between drugs for other subjective ratings provided after each song, i.e., familiarity, arousal, and emotional valence (all $P > 0.105$ Wilcoxon signed-rank tests).

五、学习音乐会让人更聪明吗?
Mozart Effect – a neuromyth?

Mozart's Sonata for Two Pianos in D Major K. 448



Rauscher, et al., 1993 Nature

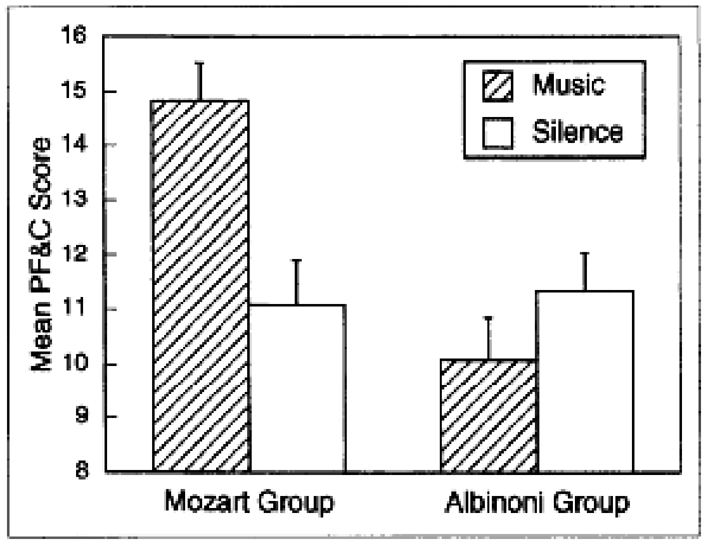


Fig. 1. Participants' mean scores on the paper-folding-and-cutting (PF&C) task after sitting in silence or listening to music. Each participant was tested in a silence condition and a music condition. Half of the participants heard Mozart in the music condition. The other half heard Albinoni. Error bars illustrate standard errors.

Arousal and Mood explains Mozart effect -->

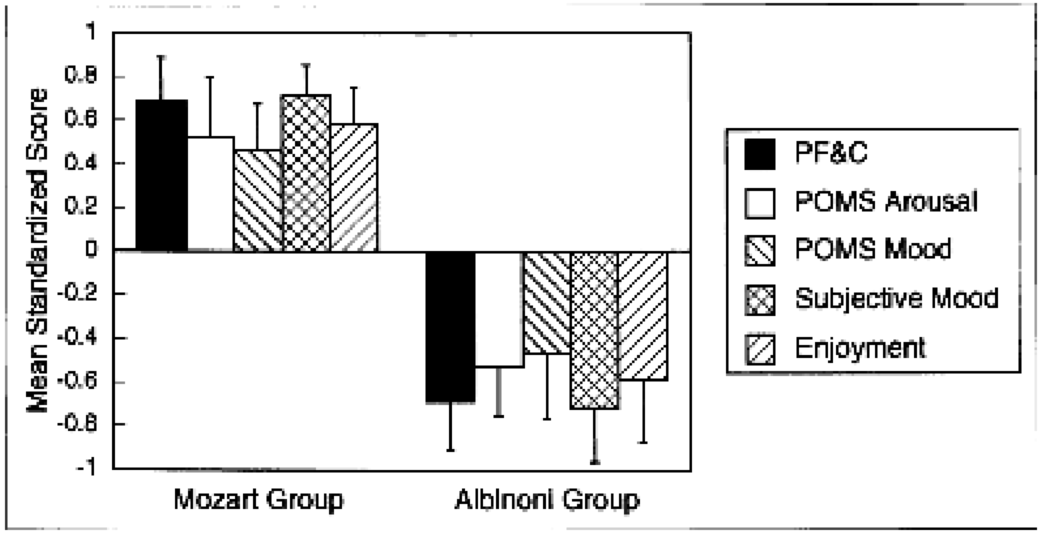
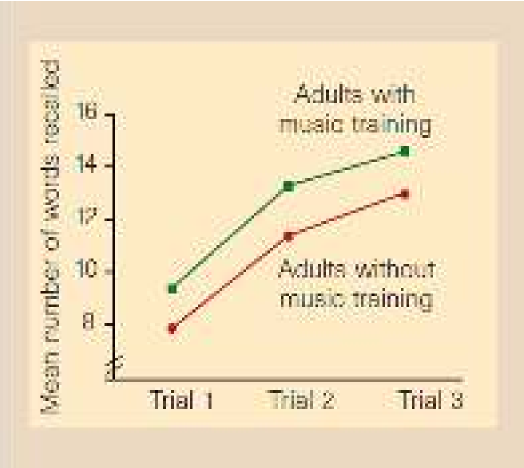


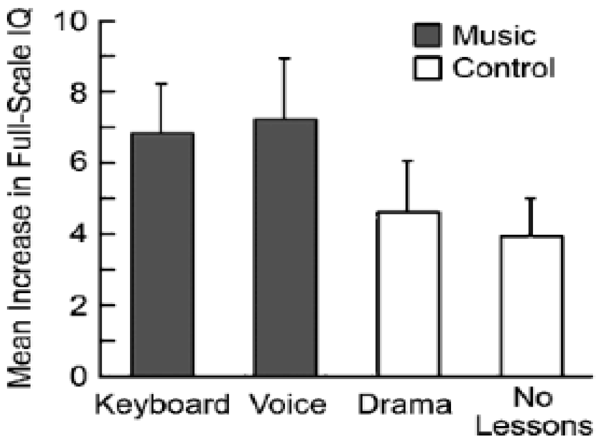
Fig. 2. Participants' mean standardized scores on five measures after listening to Mozart or to Albinoni. Scores are shown for the paper-folding-and-cutting (PF&C) task, Profile of Mood States (POMS) arousal subscale, POMS mood subscale (reverse coded), subjective mood-arousal ratings, and enjoyment ratings. Error bars illustrate standard errors.

Thompson, et al., 2001 Psychological Science

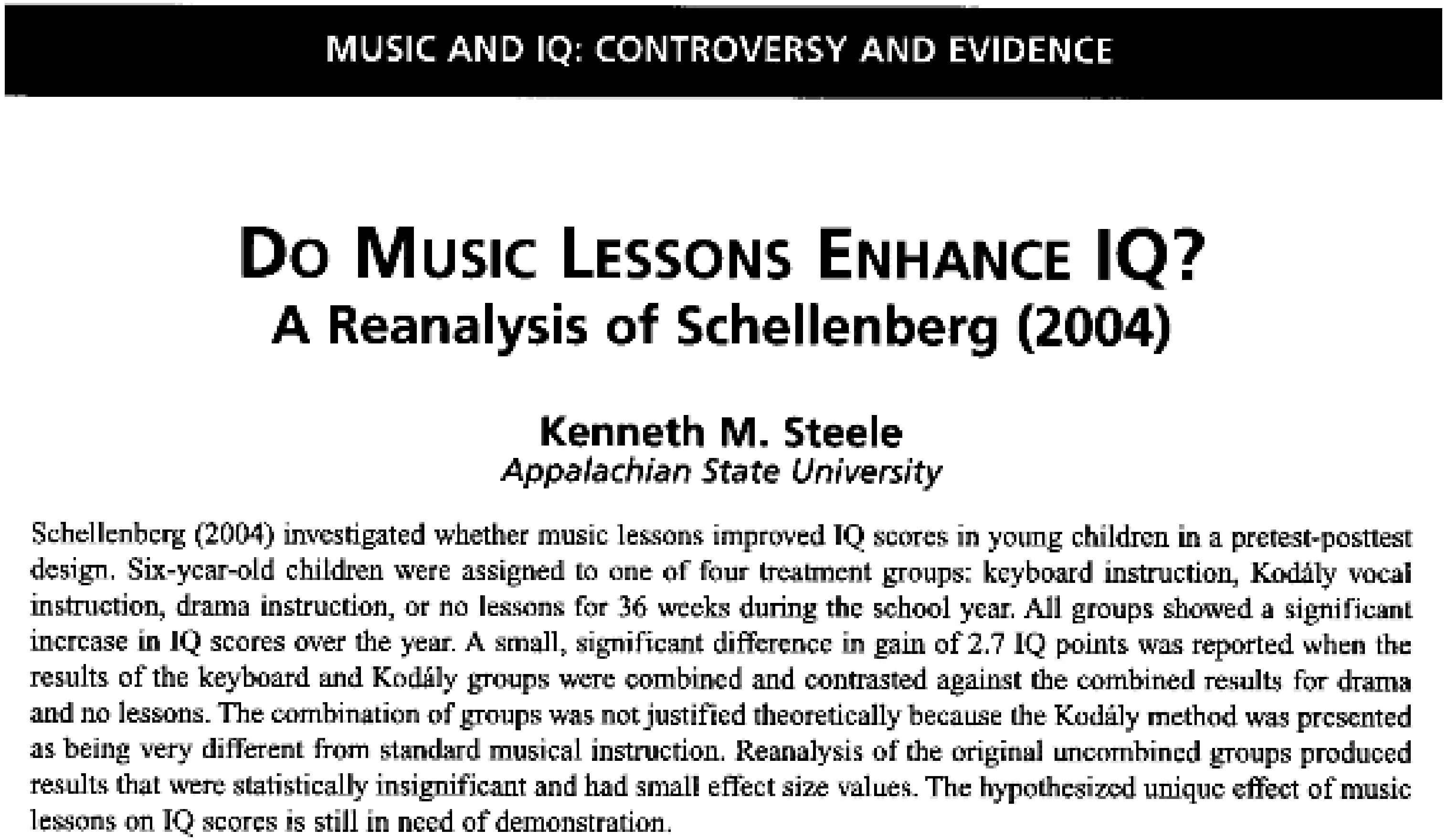
Music learning improves IQ?



Chan et al., 1998 Nature



Schellenberg, 2004 Psychological Science



MUSIC AND IQ: CONTROVERSY AND EVIDENCE

Do Music Lessons Enhance IQ?

A Reanalysis of Schellenberg (2004)

Kenneth M. Steele
Appalachian State University

Schellenberg (2004) investigated whether music lessons improved IQ scores in young children in a pretest-posttest design. Six-year-old children were assigned to one of four treatment groups: keyboard instruction, Kodály vocal instruction, drama instruction, or no lessons for 36 weeks during the school year. All groups showed a significant increase in IQ scores over the year. A small, significant difference in gain of 2.7 IQ points was reported when the results of the keyboard and Kodály groups were combined and contrasted against the combined results for drama and no lessons. The combination of groups was not justified theoretically because the Kodály method was presented as being very different from standard musical instruction. Reanalysis of the original uncombined groups produced results that were statistically insignificant and had small effect size values. The hypothesized unique effect of music lessons on IQ scores is still in need of demonstration.

Steele, 2005 The Scientific Review of Mental Health Practice

音乐学习向智商的迁移

智力方面的证据仍然有限

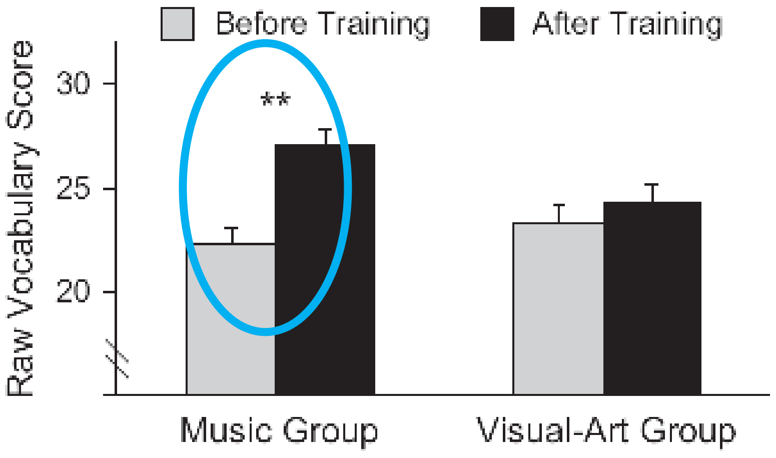


Fig. 1. Mean verbal intelligence scores before and after training as a function of training group. Vocabulary scores from the Wechsler Preschool and Primary Scale of Intelligence–Third Edition (Wechsler, 2002) were the measure of verbal intelligence. Error bars denote standard errors of the mean. Asterisks denote significant improvement (** $p < .001$).

Moreno et al., 2011. Psychological Science

	All three groups (N=74)		
subtests	pre	post	*p*
Raw score (SD)			
Vocabulary	**18.0 (4.4)**	**19.9 (5.1)**	**0.007**
Similarities	**13.4 (3.9)**	**15.89 (3.2)**	**0.001**
Animal house	**36.6 (11.2)**	**46.3 (6.9)**	**0.001**
Picture completion	**12.0 (2.9)**	**14.3 (2.9)**	**0.001**
Block design	**11.0 (4.4)**	**16.5 (2.0)**	**0.001**

	Piano (*n*=30)	Reading (*n*=28)	Control (*n*=16)	Group difference (*p*)
Mean age, months (SD)	54.7 (3.3)	54.6 (3.3)	56.6 (4.6)	0.174
Male/female	17/13	19/9	9/7	0.625
IQ (SD)	122.8 (10.9)	120.5 (12.4)	118.8 (9.9)	0.478
Digit span (SD)	12.1 (3.5)	11.3 (3.8)	12.0 (2.7)	0.664
Flanker (SD)	77.9 (18.7)	78.4 (19.9)	82.2 (19.8)	0.756

Nan et al., 2018 PNAS

总结与研究展望

基础研究

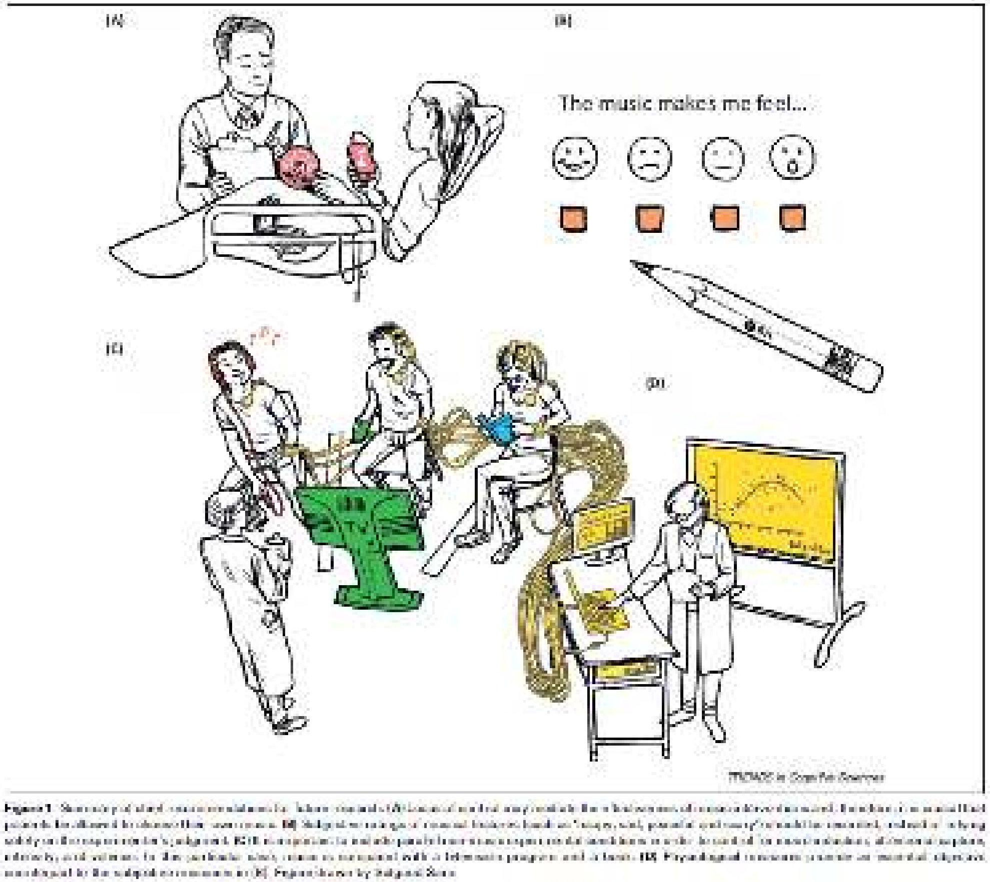
音乐加工的脑机制

教育实践

音乐学习对脑与认知的塑造

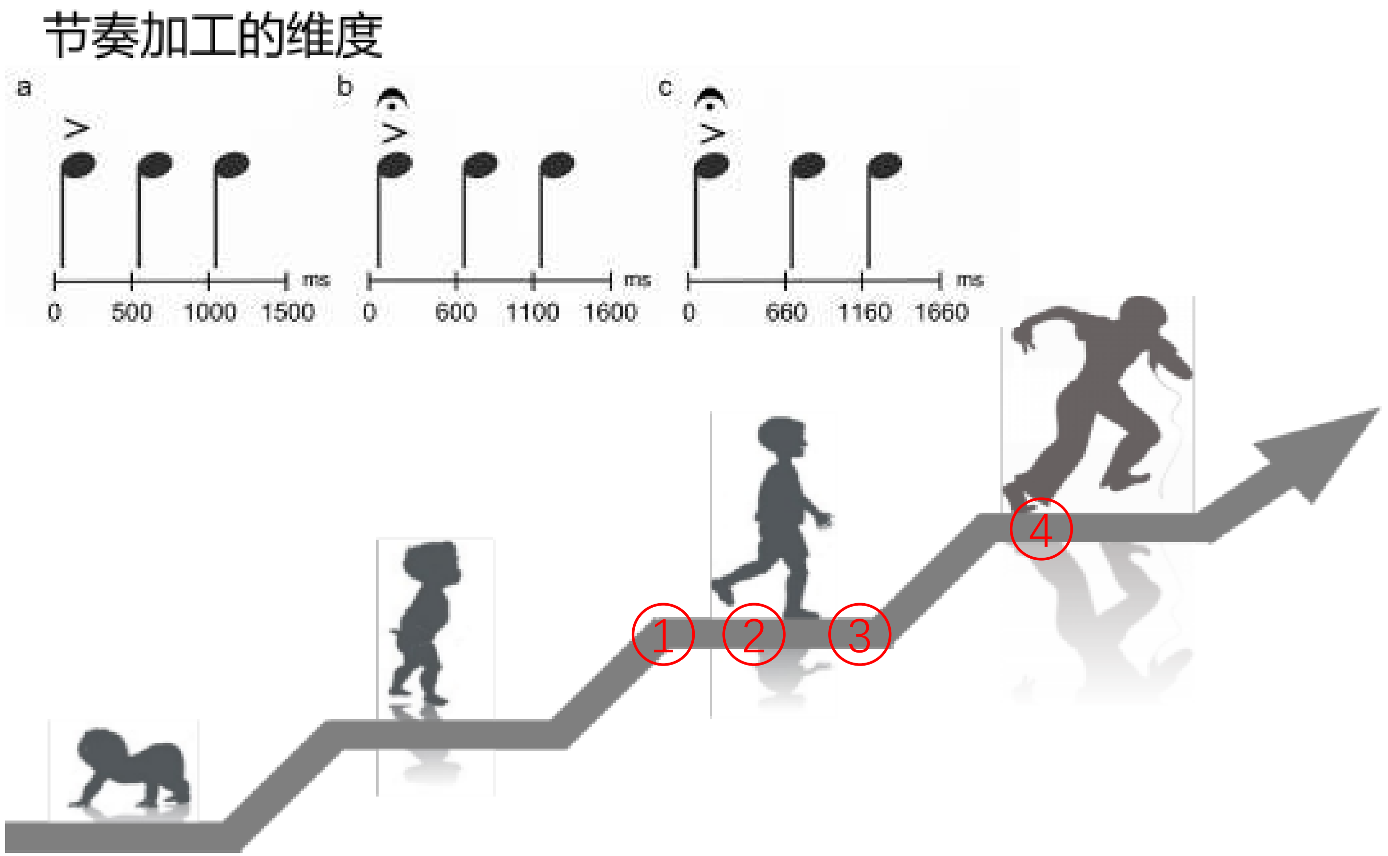
医疗应用

音乐治疗干预语言、运动、认知及发育障碍的实践及机制



Chanda & Levitin, 2013 Cell

研究展望：
儿童音乐发展轨迹及其对语言、执行功能、社会认知与脑发育的影响



1 First grade, 7 years old

2 Third grade, 9 years old

3 Fifth grade, 11 years old

4 Seventh grade, 13 years old

Acknowledgement

Thanks!

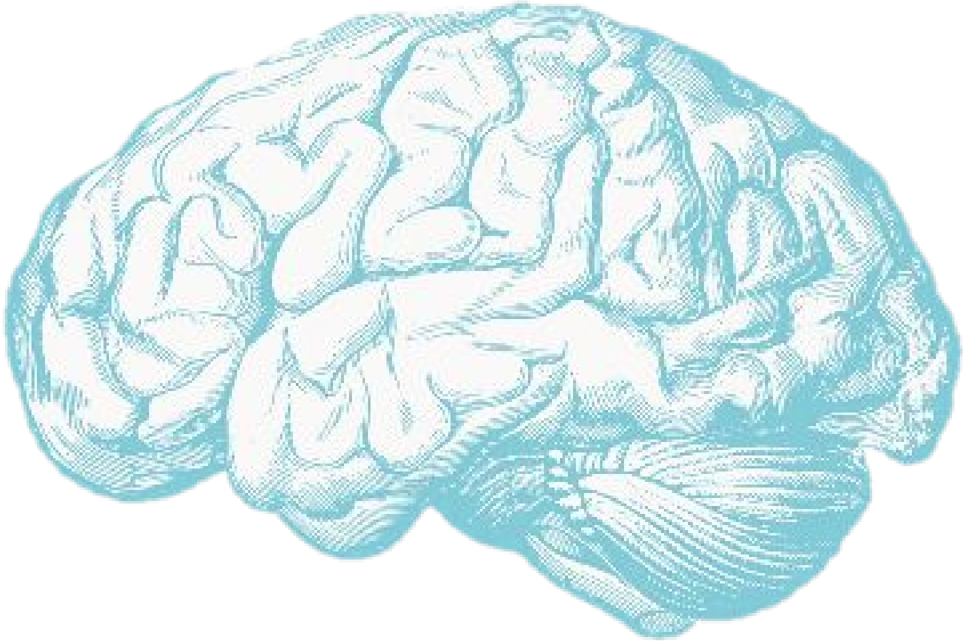
nany@bnu.edu.cn

国家自然科学基金委员会
National Natural Science Foundation of China

思考题

1、通过本节课，你对音乐与人脑的研究有什么新的认识?

2、本节课的内容中，最让你感到意外的是?



【下一讲 】
脑与认知加工：
注意