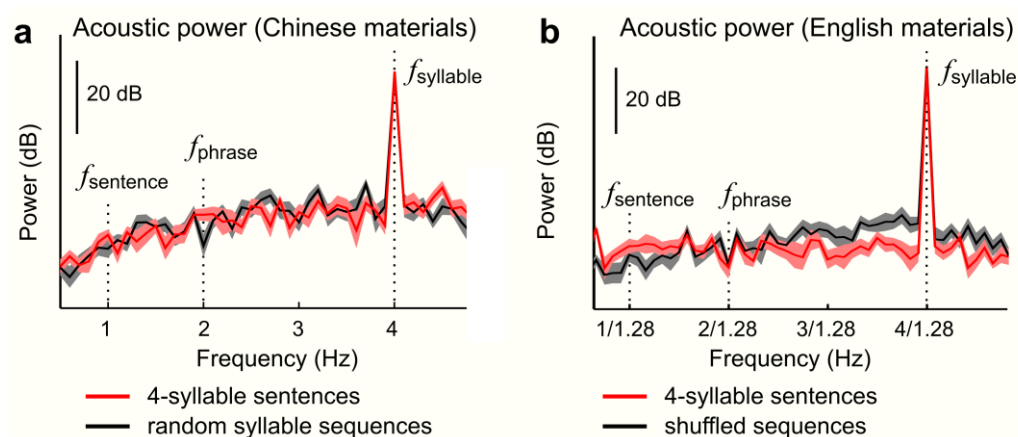


Supplementary Figure 1

Trial structure of Chinese (A-D) and English (EF) speech materials.

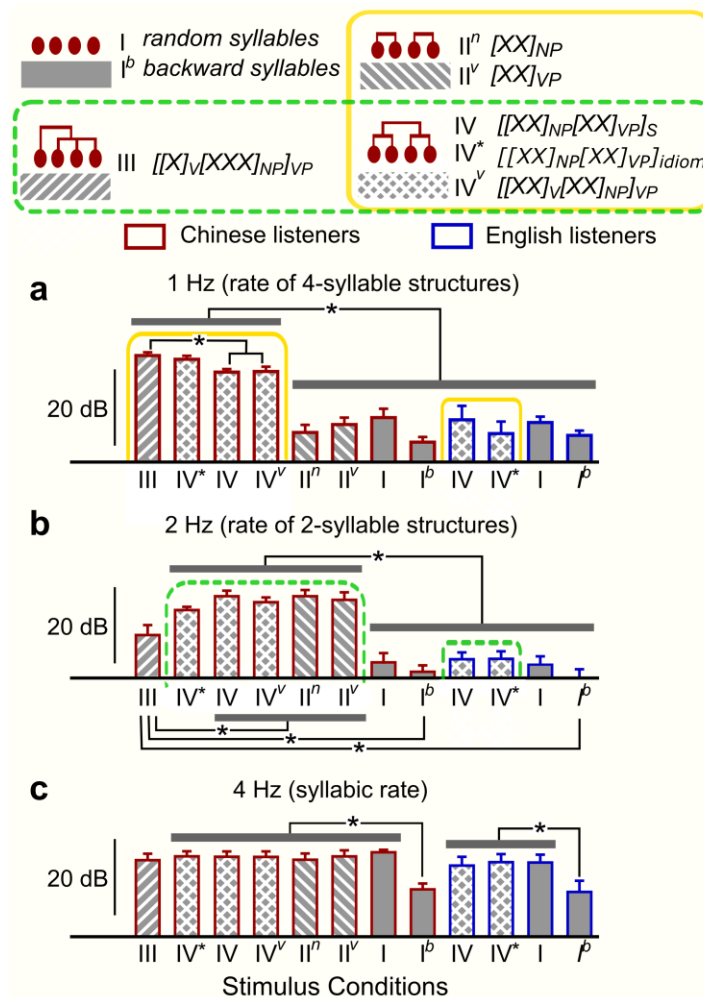
(A) For 4-syllable sentences, in each trial, 10 sentences are presented sequentially without any acoustic gap between them. English examples are given below the Chinese sentences/phrases to illustrate their syntactic structures (not direct translations). The same trial structure applies for 4-syllable verb phrases, except that each 4-syllable sentence (bounded by the dashed red box) is replaced by a 4-syllable type I verb phrase (B) or type II verb phrase (C). (D) For 2-syllable phrases, 20 phrases are presented sequentially in each trial. (E) Grammar for the constant predictability Markovian language. (F) The trial structure of Markovian language stimulus.



Supplementary Figure 2

The spectrum of the temporal envelope for the Chinese (A) and English (B) 4-syllable sentence stimuli.

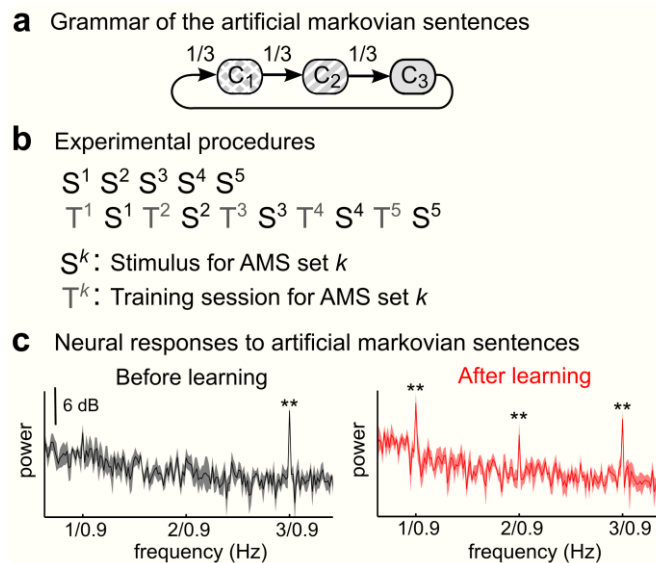
The power spectrum is averaged over all stimulus trials, and the SEM across trials is shown (shaded area). A spectral peak is seen at the syllabic rate but not at the phrasal or sentential rates, confirming that the sentential and phrasal structure is not conveyed by acoustic power cues. The stimulus envelope is the half-wave rectified sound waveform. The two conditions shown for each language are not significantly different from each other ($P > 0.15$, FDR corrected).



Supplementary Figure 3

Comparisons between the responses to stimuli of different linguistic structures.

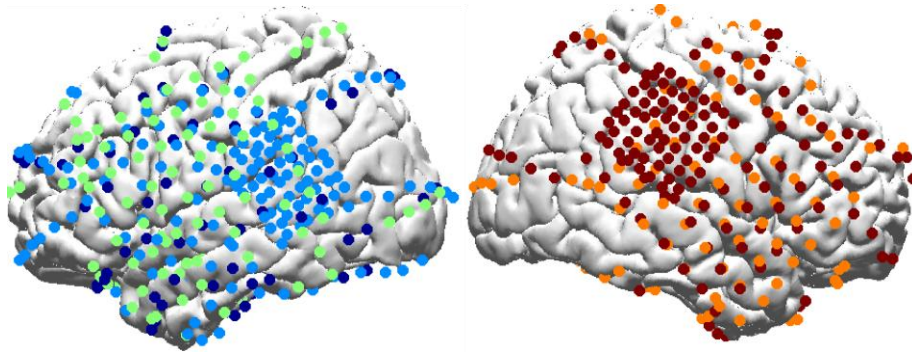
The tree diagrams at the top illustrate the four linguistic structures tested. All of them are constructed using an isochronous syllable sequence at 4 Hz. For Structure I, syllables or backward syllables are presented in a random order, not grouped into larger linguistic structures. For Structure II, every two syllables combine into a phrase, which activates a phrasal rhythm at 2 Hz in addition to the 4-Hz syllabic rhythm. For Structure III, a 4-syllable verb phrase is constructed using a monosyllabic verb followed by a 3-syllable noun phrase. The 4-syllable verb phrase is frequency-tagged at 1 Hz but no linguistic structure is uniquely tagged at 2 Hz. For Structure IV, a 4-syllable structure evenly divides into two 2-syllable structures. The binary hierarchical embedding results in three levels of linguistic structures tagged at 1 Hz, 2 Hz, and 4 Hz, respectively. (A) For Chinese listeners (dark red bars), the 1-Hz response is significantly stronger for stimuli containing a 4-syllable constituent structure (yellow box). For English listeners who cannot parse the linguistic structure (blue bars), however, the response is not significantly different between conditions. All significant differences between conditions are shown and a thick gray bar indicates significant differences between two groups such that each condition in one group is significantly different from any condition in the other group ($P < 0.03$, t-test, FDR corrected). (B) The response at 2 Hz is stronger for stimuli containing 2-syllable phrasal structures (dashed green box) for Chinese listeners, but not so for English listeners. (C) A 4 Hz response, at the syllabic rate is seen in all tested conditions and both listener groups, but weaker for backward syllables than normal syllables.



Supplementary Figure 4

Dissociating neural encoding of sentential structures and transitional probability using Artificial Markovian Sentences (AMS).

(A) Grammar of the AMS. Each AMS consisted of 3 components, and each syllable was independently chosen from 3 candidate syllables with equal probability. In each trial, 33 sentences were played in a sequence without any gap in between them. (B) Procedures of the AMS experiment. The experiment has two sessions. In the first session (upper row), stimuli from each set of the AMS were played in separate blocks, before the listeners were instructed about the grammar of the AMS. In the second session, the 5 sets of AMS were learned in separate blocks. In the training phase of each block (labeled by T), the listeners listened to sentences from the AMS set and these sentences were separated by a 300 ms gap. After the training phase, the listeners listened to the same stimuli they heard in the first session. At the end of the block, the listeners had to report the grammar of the AMS set. (C) Neural response spectrum before (left) and after training (right). Before the listeners learn the grammar of the AMS, cortical activity only tracks the syllabic rhythm of speech. After learning, however, cortical activity concurrently follows the syllabic rhythm and the sentential rhythm. Since each trial (excluding the first sentence) is 53.1 seconds in duration, the frequency resolution of the spectrum is 0.019 Hz. Frequency bins showing power stronger than the mean power of a neighboring 1 Hz region (i.e., 0.5 Hz on each side) are shown by stars ($N = 5$, $P < 0.001$, paired t-test, FDR corrected).



Supplementary Figure 5

Coverage of the ECoG electrodes.

Color differentiates the 5 participants.

Table S1, Chinese sentence materials

Chinese 4-syllable sentences

老牛耕地	朋友请客	厨师做饭	电脑开机	游客爬山
树木生长	汽车拐弯	外公看报	轮船起航	渔民划船
冰雪融化	灯泡发光	婴孩啼哭	士兵战斗	军队撤退
小孩哭泣	农民种菜	鸭子游泳	蝴蝶飞舞	剪刀生锈
猎豹奔跑	青草发芽	和尚念经	蜘蛛结网	祖父下棋
老师讲课	太阳落山	鲸鱼喷水	公司开张	医生看病
绵羊吃草	开水沸腾	小偷逃走	兄弟吵架	护士打针
学生写字	导游讲解	熊猫睡觉	骏马奔驰	乌龟爬行
观众鼓掌	叛徒告密	英雄救火	母鸡下蛋	行人过街
演员跳舞	苹果成熟	狮子打架	飞机降落	法官判案

Chinese 4-syllable verb phrases comprised of 1-syllable verb followed by a 3-syllable noun phrase.

蒸灌汤包	熬银耳羹	戴老花镜	拍婚纱照	炒西红柿
买笔记本	敲架子鼓	念金刚经	过独木桥	擦防晒霜
摊鸡蛋饼	吃哈密瓜	演古装剧	拉大提琴	喝矿泉水
坐头等舱	吹单簧管	上历史课	打保龄球	切土豆丝
品乌龙茶	当志愿者	骑小毛驴	练太极拳	跑马拉松
修自行车	说普通话	养波斯猫	登长白山	嚼口香糖
捉萤火虫	听收音机	读红楼梦	考公务员	饮庆功酒
煮茶叶蛋	剥香蕉皮	泡方便面	种仙人掌	唱黄梅戏
开杂货店	讲闽南语	卖羽绒服	办身份证	榨花生油
付水电费	写毛笔字	换电灯泡	穿中山装	煎三文鱼

Chinese 4-syllable verb phrases comprised of 2-syllable verb followed by a 2-syllable noun.

举行比赛	制作节目	承担责任	浏览网页	缝合伤口
享受生活	发表言论	抓住机会	演唱歌曲	美化环境
伪造证据	召开会议	拜访亲友	点燃蜡烛	背诵散文
修理电脑	复习功课	拼写单词	看望老师	裁剪衣服
做出决定	寻求支持	捕捉昆虫	砍伐森林	装修房间
关闭大门	展示成果	播放广告	破坏气氛	解决问题
准备午饭	弹奏钢琴	支援灾区	等待时机	订阅期刊
饲养金鱼	总结教训	收集资料	粉刷墙壁	训练军队
种植青菜	打印文件	改正错误	绘制地图	购买设备
判断形势	批改试卷	整顿秩序	维护尊严	阅读书籍

Chinese 4-syllable idioms

杞人忧天	毛遂自荐	塞翁失马	星火燎原	蜻蜓点水
骄兵必败	百花齐放	本性难移	鸚鵡学舌	老骥伏枥
危言耸听	飞黄腾达	飞蛾扑火	余音绕梁	金蝉脱壳
肝肠寸断	愚公移山	滥竽充数	玉树临风	金鸡独立
精卫填海	八仙过海	蓬荜生辉	众星捧月	盛气凌人
天花乱坠	白驹过隙	孟母三迁	怒发冲冠	万象更新
本末倒置	死灰复燃	庖丁解牛	孤掌难鸣	韦编三绝
山雨欲来	螳臂当车	破镜重圆	光阴荏苒	心血来潮
声名鹊起	醍醐灌顶	七窍生烟	归心似箭	新陈代谢
茅塞顿开	短兵相接	烽火连天	花枝招展	盲人摸象

Chinese sentences varying in length and syntactic structure

理论要与实际结合	曼哈顿是一个岛	白云在天上飘	暴风雪来临	地动山摇
外面的世界很精彩	没有钱是不行的	鲜花逐渐凋零	贵人多忘事	打乒乓球
现在是二零一四年	将来生活会更好	红苹果最好吃	要抓住机会	准备出发
火车站今天不售票	驾驶一辆公交车	细雨下个不停	收到一封信	青草发芽
上海房价持续增长	门外有辆出租车	微风吹过水面	手术很成功	我要吃饭
浪费资源是可耻的	我喜欢上化学课	钱不是万能的	民以食为天	雨还在下
汽车在公路上行驶	孙悟空变化多端	阳光照进屋里	作业没写完	铁证如山
开会之前做好准备	谣言是不可信的	历史不会重演	西湖在杭州	创造奇迹
目前形势变得紧张	几个小孩在玩耍	我喜欢开玩笑	日久见人心	万马奔腾
中国人口比美国多	敌人隐藏在树后	公园建在山上	你不要害怕	祝你好运
这是一个民间传说	海边有很多贝壳	中国人口很多	为自由而战	乌云密布
研究中国传统文化	表哥在大学读书	他在澳大利亚	饭前请洗手	多加小心
黑龙江在中国东北	游乐场非常好玩	昨天已经过去	向前辈致敬	雄鹰展翅
对面是一座博物馆	社会问题很严重	天安门在北京	海上升明月	勤奋工作
为中华崛起而读书	冬天要注意保暖	温度慢慢降低	购买电视机	风沙很大
埃及有很多金字塔	一颗苹果掉下来	虚心使人进步	唱一支山歌	公鸡打鸣
这件事情务必办好	乡间小路不好走	这是关键问题	小孩学游泳	军队撤退
大雪造成航班取消	作业要按时完成	假期已经结束	江水向东流	明天放假
下周末我们去度假	好心必定有好报	这本书看不懂	保护大熊猫	树立榜样
一个人旅行要小心	使用笔记本电脑	天机不可泄露	阿姨去上班	复印文件
他在写一封推荐信	森林里生机盎然	飞机将要起飞	周末要加班	春光明媚
华盛顿是美国首都	河马是非洲动物	树林里有小鸟	哈密瓜很甜	开卷有益
始祖鸟是鸟类祖先	我要做有用的人	王老师教数学	乌鸦是黑的	高楼林立

海鸥在暴雨中翱翔	天下乌鸦一般黑	金钱豹跑得快	外公下象棋	刻舟求剑
士兵以服从为天职	小朋友们多高兴	时间过得真快	公交车到站	繁星满天
早上起来先要洗脸	那个同学真聪明	鲨鱼非常凶猛	天上飘雪花	鸡飞狗跳
加拿大比美国寒冷	这条围巾真漂亮	山上有座凉亭	白兔吃青草	美化环境
骆驼生活在沙漠里	上课要认真听讲	今天事情太多	大熊猫睡觉	苦尽甜来
餐馆里的灯光暗淡	人逢喜事精神爽	每天都要刷牙	酒后吐真言	熟能生巧
请大家系好安全带	勿以善小而不为	吃完饭就出发	我在打电话	天气真好
红烧牛肉面真好吃	偷鸡不成蚀把米	勇攀科学高峰	学习古汉语	不要紧张
探索大自然的奥秘	考试之前要放松	认真学习功课	周六不上课	河水结冰
猫头鹰在夜间活动	早饭一定要吃饱	最近心情很好	出门向前走	浏览网页
好习惯要从小养成	公园里有大草坪	从此不再迷茫	小松鼠逃跑	种植蔬菜
早睡早起是好习惯	邮递员送来包裹	要从小事做起	修理自行车	把他赶走
共同创造美好生活	年轻人要有理想	以天下为己任	礼轻情意重	轮船启航
动物园里有长颈鹿	图书馆开门很早	喝茶有益健康	请帮我开门	他在跑步
两支军队一起出发	不到长城非好汉	阅读古典名著	自扫门前雪	马上集合
教室里面不能喧哗	彩虹总在风雨后	烹调可口蔬菜	她还在吃饭	播放音乐
太阳系有九大行星	树上的松鼠真多	维护法律尊严	快刀斩乱麻	百花齐放

Chinese sentences varying in the duration of the noun phrase (3-syllable noun phrase)

玻璃杯要轻拿轻放	三个人一起去吃饭	两匹马飞快的奔跑	那顿饭吃得不错
我们俩明天去旅游	那些人非常有经验	老校长将要退休	博物馆周日关门
旧报纸不容易找到	运动会推迟一礼拜	小组长办事认真	登山包能够防雨
公务员为人民服务	天王星离地球很远	小松鼠跳来跳去	市政府下达指示
旅游团马上就出发	俄罗斯比中国寒冷	这首歌格外好听	金项链不翼而飞
董事长在布置任务	天安门坐落在北京	四季豆还没做好	施工队停止工作
父母亲最近都很好	西红柿富含维生素	张先生拒绝签字	发动机出现故障
大熊猫喜欢吃竹子	洛杉矶位于西海岸	电影票已经卖完	猫头鹰张开翅膀
辅导员今天要出差	外祖父对我非常好	敞篷车特别凉快	花围巾十分漂亮
长颈鹿是非洲动物	战士们为自由而战	旧电池需要回收	
王老师很关心学生	加拿大盛产三文鱼	班主任大发雷霆	
毒蘑菇长得很鲜艳	科学家提出新理论	足球赛仍未结束	

Chinese sentences varying in the duration of the noun phrase (4-syllable noun phrase)

羽毛球拍挂在墙上	一切问题迎刃而解	股票价格大幅振荡	几只猫咪刚出生
大暴风雪即将来临	这个小孩很有前途	今年冬天格外冷	蓝色外套蛮好看

红烧牛肉非常好吃	新款服装降价促销	一片树叶飘下来	两只蜜蜂采花蜜
联欢晚会正式开始	电视节目枯燥无味	鲜榨果汁有营养	黑玫瑰花不常见
厚羽绒服可以御寒	个别同学没来上课	茉莉花茶真好喝	副总经理来参观
贵重物品随身携带	很多难题未能解决	夫妻两人都不在	大量警察在巡逻
新鲜牛奶有益健康	热血青年奋起抗争	那头黄牛在耕地	重要文件被偷走
公司财政十分紧张	鹅毛大雪下个不停	一只气球飞上天	考试题目挺简单
五星红旗迎风飘扬	期末考试因故取消	他的想法最特别	有些动物会游泳
强冷空气来自北方	满天星抖闪闪发光	淡水资源要珍惜	
美元汇率继续上杨	河边柳树发出嫩芽	古代汉语很难懂	
女服务员工作勤奋	总设计师绘制蓝图	白葡萄酒有点甜	

English 4-syllable sentences comprised of a 2-syllable noun phrase followed by a 2-syllable verb phrase.

fat rat sensed fear	kind words warm hearts	young child closed doors
wood shelf holds cans	long fight caused hate	thin threads hang plates
tan girls drove trucks	dead sharks leak blood	their store sold cars
gold lamps shine light	smart dogs dig holes	cute cubs drink milk
dry fur rubs skin	slim kids like jeans	six farms lost cows
sly fox stole eggs	sick boys fail tests	sharp knife cuts cheese
top chefs cook steak	rear doors hide cups	round soap killed germs
our boss wrote notes	pale hands make bread	loud sound scared mom
two teams plant trees	bad smells fill town	weird clowns wear hats
all moms love kids	mad foes smack chefs	her sons paint walls
new plans give hope	quiet lamb ate grass	giant bears cross streets
large ants built nests	soft fork brings food	drunk dudes sang hums
teen apes hunt bugs	green frogs miss flies	little chick caught worms
rude cats claw dogs	black skies show stars	brown bags take space
rich cooks brewed tea	tall guys flee camp	four maids cleaned rooms
fun games waste time	gray goat climb hills	big rocks block roads
pink toys hurt girls	iced beer costs cents	fierce flood ruined farms
huge waves hit ships	old kings gave speech	warm ground melts snow
deaf ears hear you	blue eyes shed tears	keen blades slash tires
his aunt tied shoes	white cars need gas	poor friends paid bills

English predictable Markovian sentences

a girl	found	the key
the cake	tastes	great
coffee	keeps me	awake
dad	ordered	salad
mom	cooks	dinner

they	grow	apples
fish	lives in	water
earning	money	is hard
homework	needs to	be done
progress	has been	made
my cat	is so	lovely
New York	never	sleeps
I will	buy a	book
he will	take the	train
parents	became	worried
rumors	are not	true
boys	play	football
dogs	can be	smart
Nancy	works	at home
Keith	went to	college
Matt	married	carol
Amy	owns a	farm
Sarah	looks	happy
Emma	hates	Alice
Lauren	came	early

The grammar for AMS set. The 3 candidate syllables for each component are listed.

	AMS Set 1	AMS Set 2	AMS Set 3	AMS Set 4	AMS Set 5
C1	qiū	hā	chóu	guī	liú
	dá	shuài	juàn	lǐ	cā
	huà	nóng	biǎo	kòu	tián
C2	zhāng	lǚ	zāi	tāo	xiào
	rě	péi	xián	qí	lǚ
	yuè	dīng	huì	jūn	niè
C3	miǎn	rì	wēn	xíng	fǒu
	jú	mǎng	qiǎng	zǔ	gé
	duì	zhuī	luè	mǒu	zhuàng

Table S2. Behavioral performance for all experimental conditions (mean \pm SEM). The miss rate and the false alarm rate are averaged to create an average error rate.

Exp 1	4-syllable sentences	4-syllable idioms	random syllables	backward syllables	
	18.8 \pm 13.8%	9.4 \pm 9.8%	14.4 \pm 12.7%	20.6 \pm 24.7%	
Exp 2	4-syllable sentences	4-syllable VP (type I)	4-syllable VP (type II)	2-syllable NP	2-syllable VP
	12.8 \pm 3.5%	4.1 \pm 2.0%	20.0 \pm 3.0%	22.5 \pm 5.6%	20 \pm 6.0%
Exp 3	Sentences with variable duration and syntactic structures				
	9.4 \pm 2.5%				
Exp 4	Sentences with variable NP durations				
	23.5 \pm 4.7%				
Exp 5	4-syllable sentences	4-syllable idioms	random syllables	backward syllables	
	36.3 \pm 6.4%	46.3 \pm 6.1%	40.0 \pm 4.0%	45.6 \pm 3.8%	
Exp 6	4-syllable sentences	shuffled sentences	unpredictable Markovian sentences	predictable Markovian sentences	
	37.9 \pm 4.3%	17.3 \pm 4.0%	22.3 \pm 6.0%	6.5 \pm 3.4%	