Measuring the Influences of Musical Parameters on Cognitive and Behavioral Responses to Audio Notifications Using EEG and Large-scale Online Studies

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Timbre

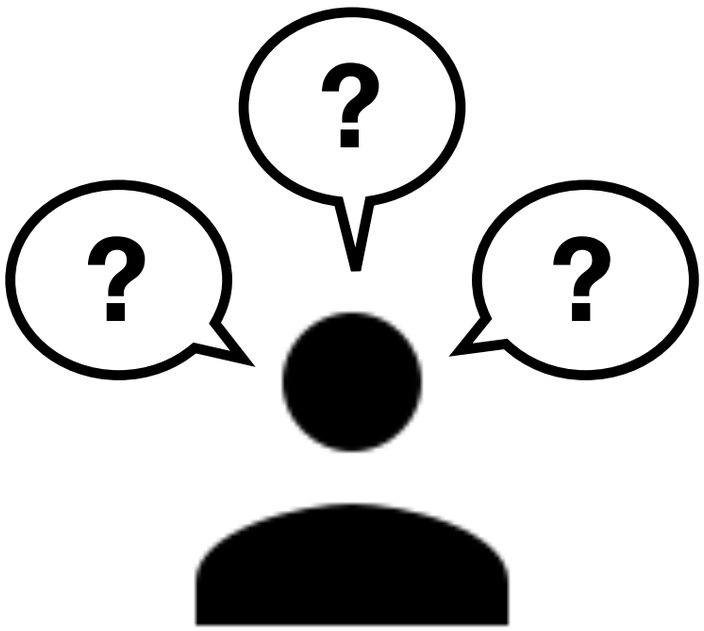
Melody

Pitch

Tempo

Musical parameters can influence notifying effect of audio notifications

[Brewster et al., 2002; Edworthy et al., 2006; Garzonis 2009; Setlur et al., 2014]



Integration of cognitive measures

[Frauenberger et al., 2009]

Different users & environments

[Frauenberger, 2009; Liljedahl, 2010; Ghosh, 2015]

Focus on these two issues

Goal

Understand how changes in musical parameters influence notifying effect of audio notifications

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EEG Study

Electroencephalography

Record electrical activities of brain; observe cognitive responses

Large-scale Online Study

Behavioral responses from a larger & more diverse sample of participants

Musical Parameters

- **Melody**: Simple, Complex (musically trained raters)
- **Pitch**: Low, High (+500 cents = half octave)
- **Tempo**: Slow (120 BPM), Fast (200 BPM)
- **8** notifications

[Edworthy, 1999; Komatsu, 2010; Liljedah, 2010]

EEG Study

Measures of Cognitive Responses

Auditory Stimuli

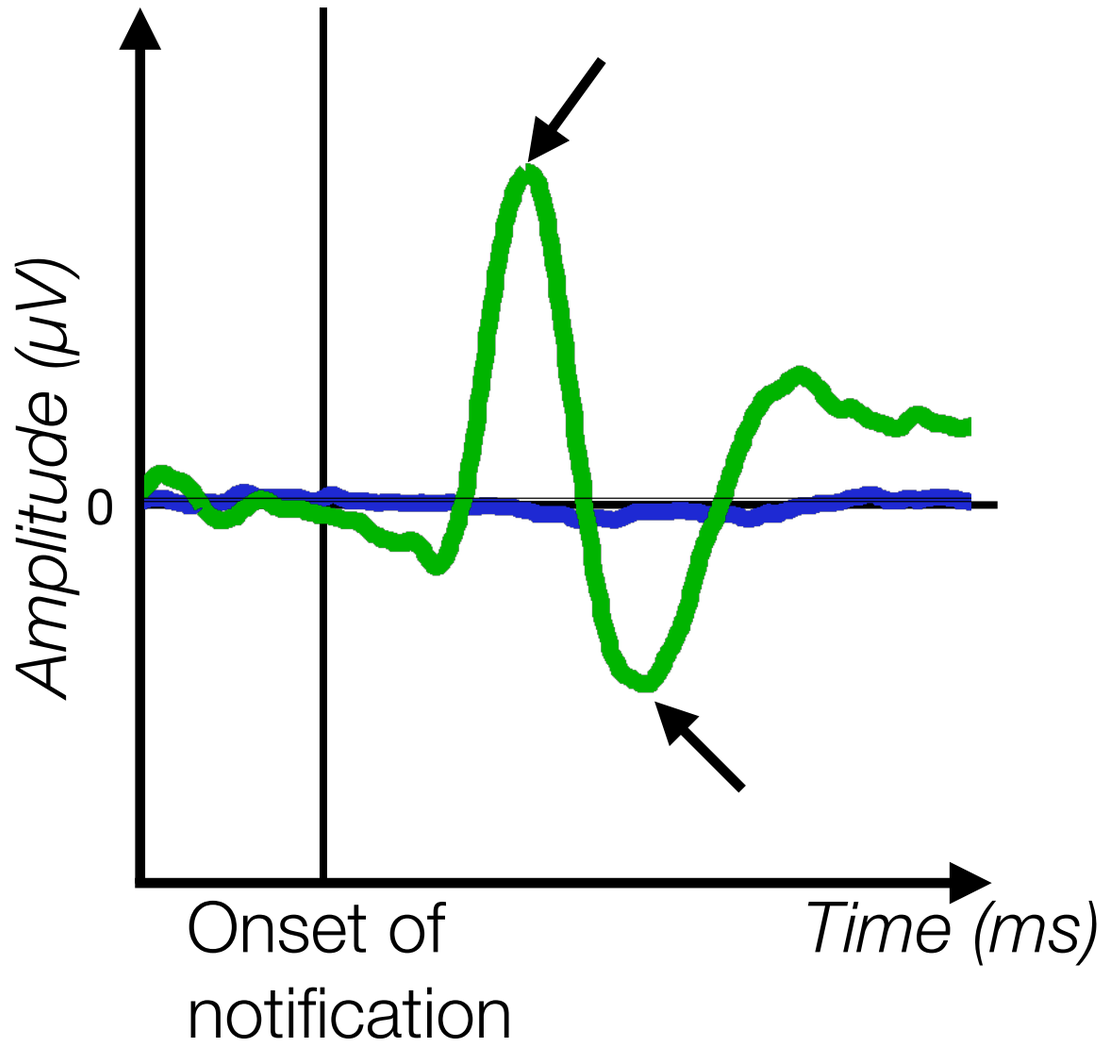
Audio notification

Ambient sound

MMN & P3a

Audio notification

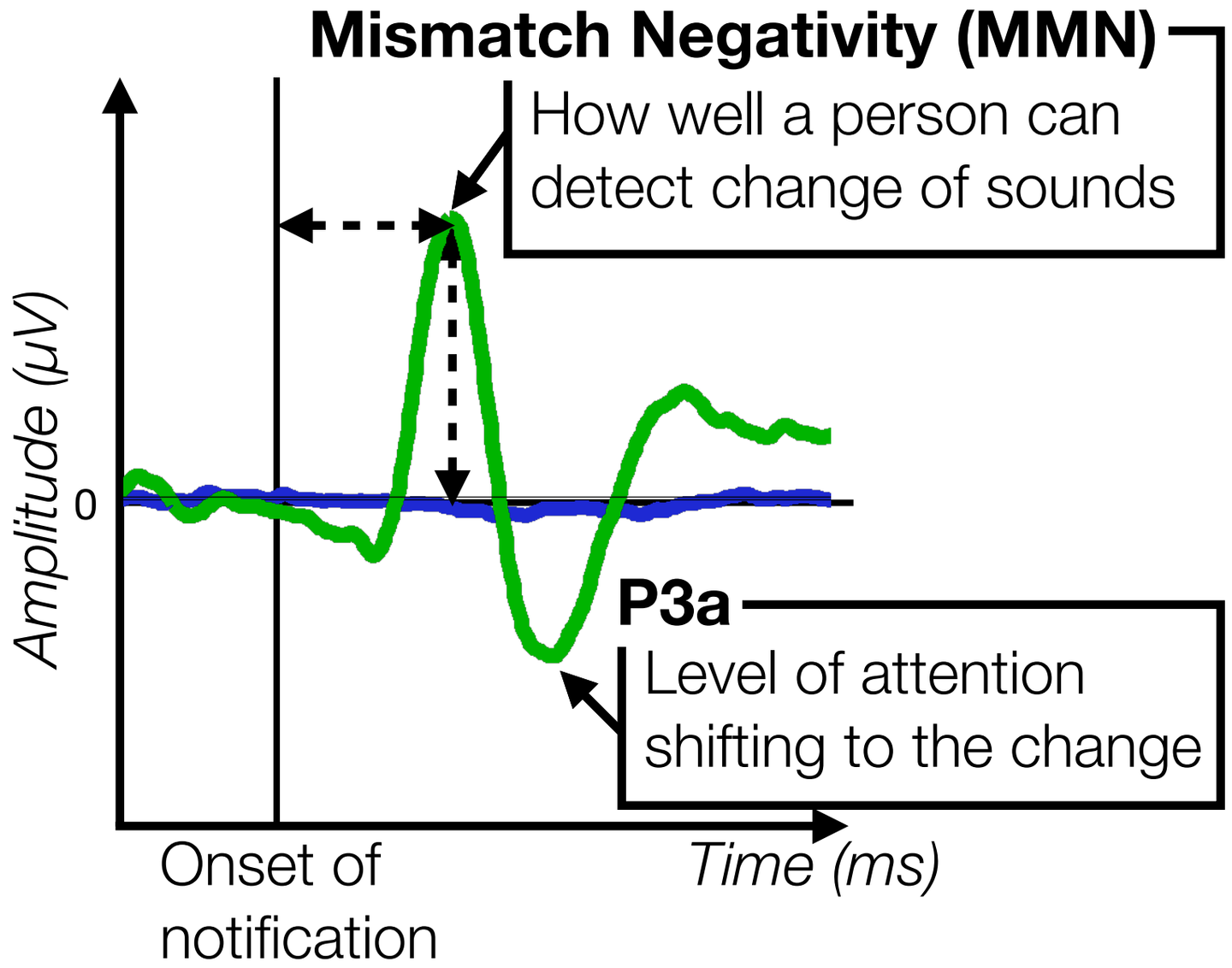
Ambient sound



MMN & P3a

Audio notification

Ambient sound



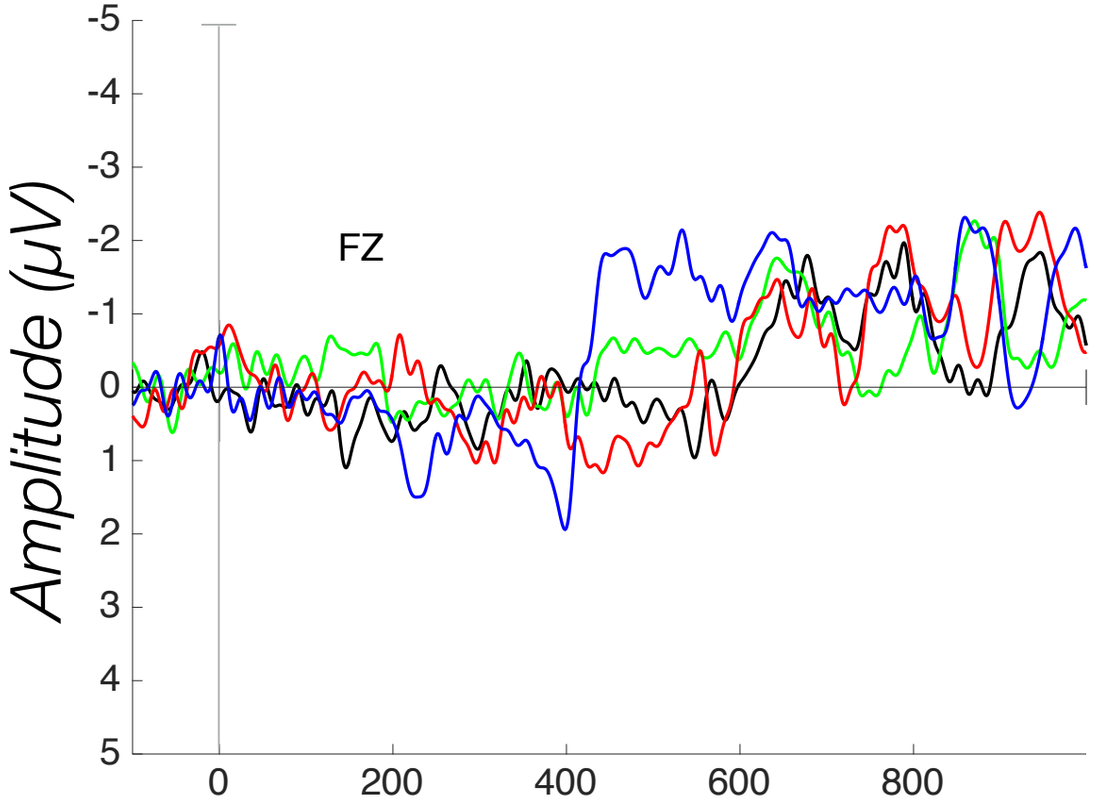
Experiment Setting

- 20 participants (7 males, 20-28 years old)
- Focus on watching silent film; we played auditory stimuli
- Record EEG (MMN & P3a)

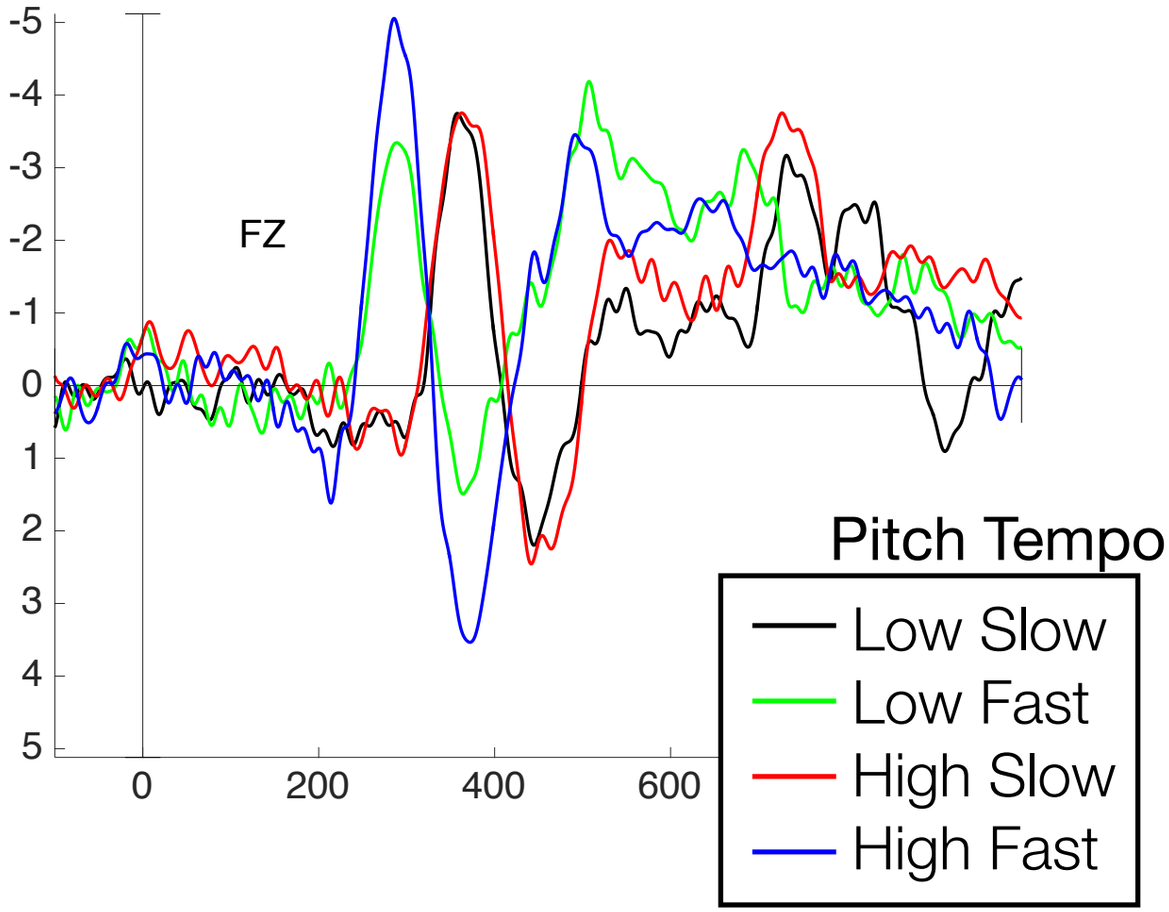
Result

EEG Waveform

Complex Melody



Simple Melody

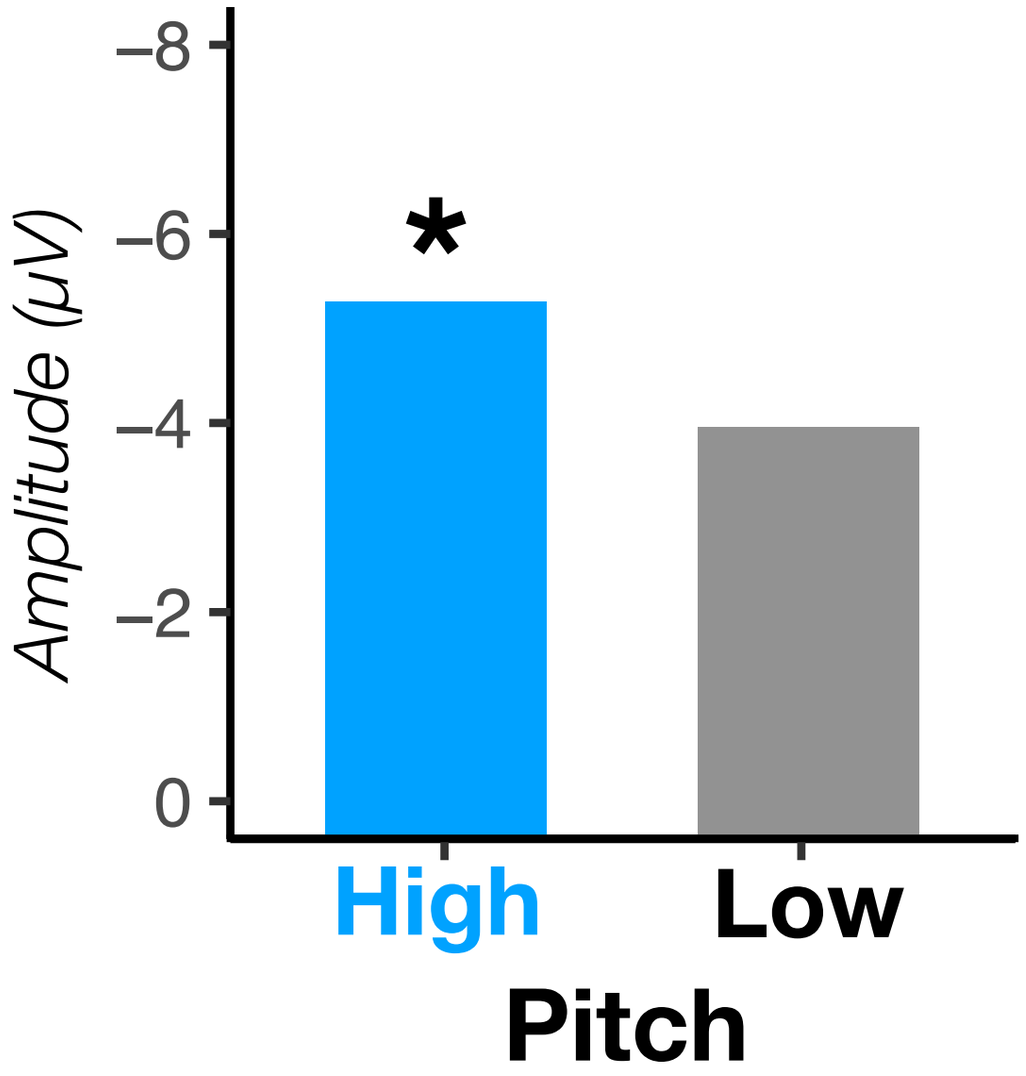


Complex melody didn't evoke **obvious** MMN and P3a like simple melody

Result

Amplitude of Cognitive Responses
in Condition of Simple Melody

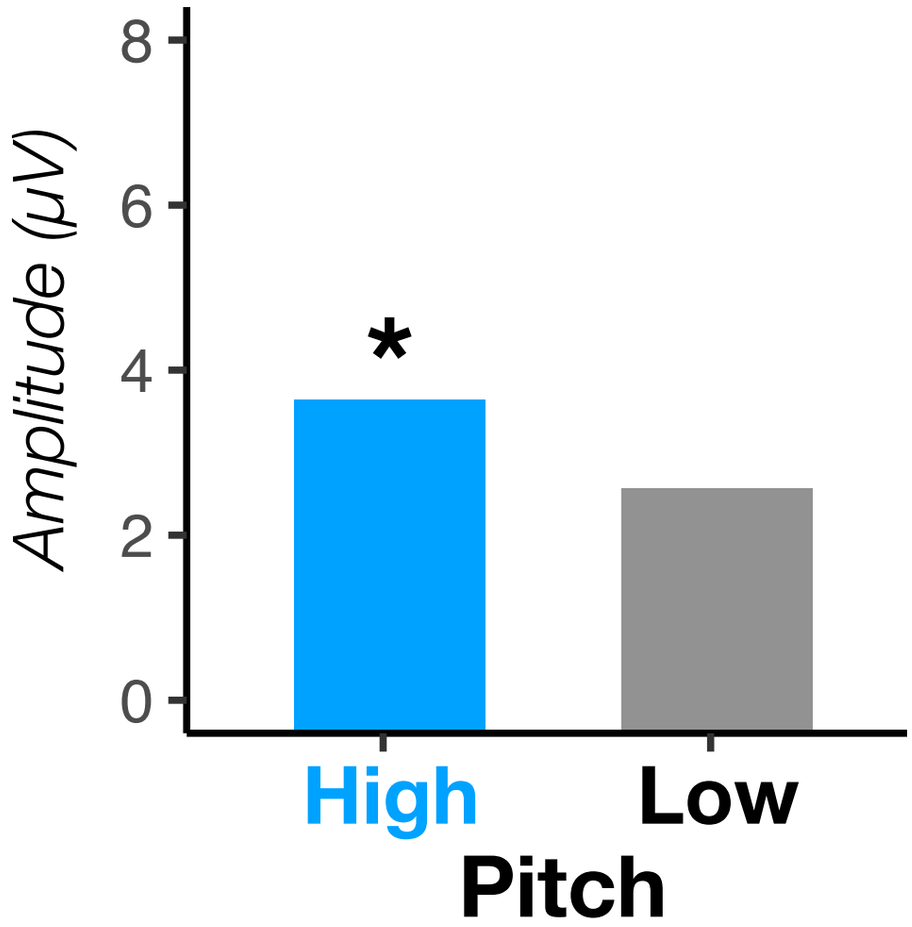
Auditory Detection (MMN)



High pitch is more easily to be **detected**

Fast Tempo

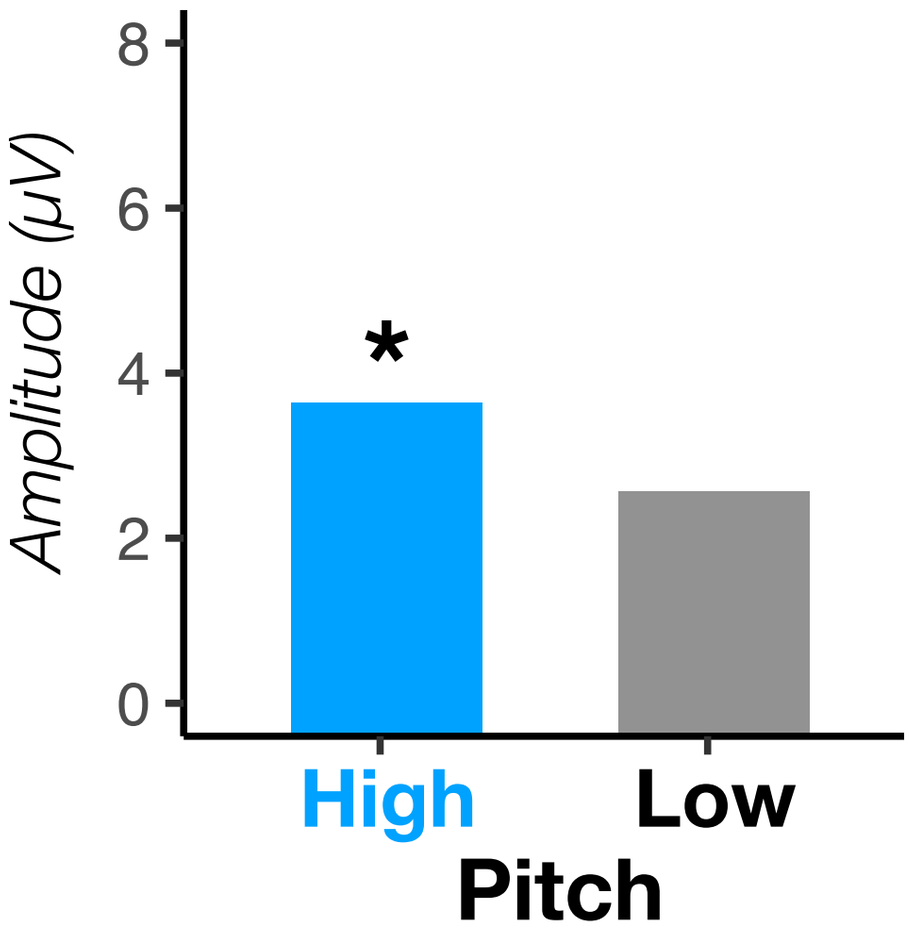
Attention shifting (P3a)



In **fast tempo** condition, **high pitch** shifts **more attention**

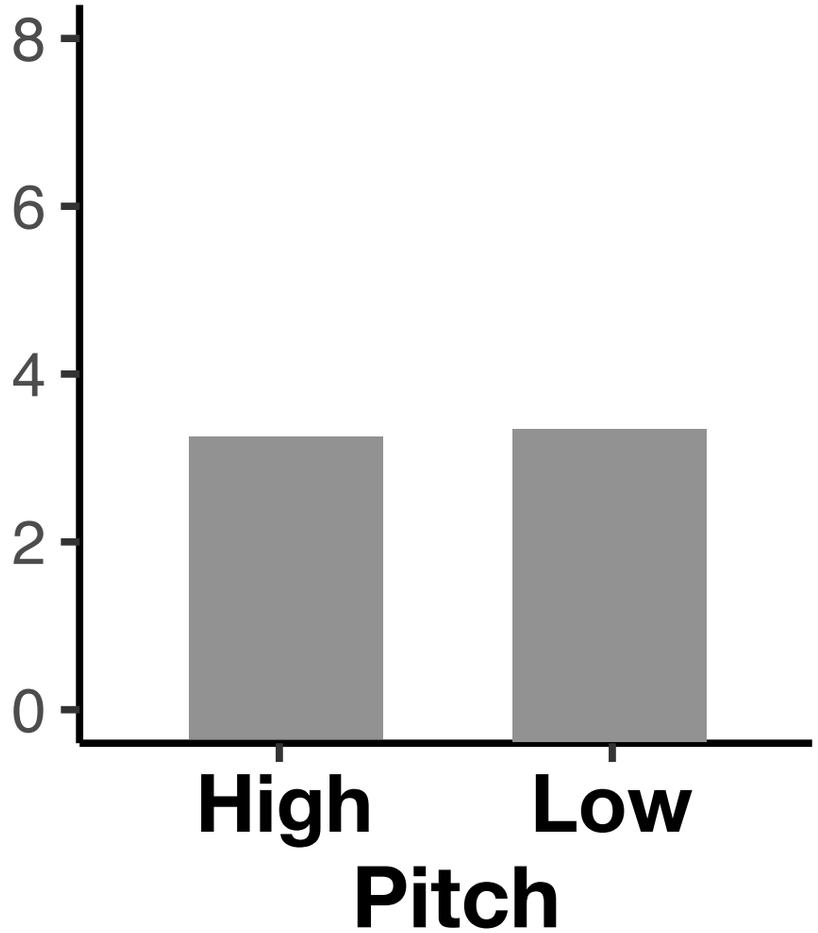
Fast Tempo

Attention shifting (P3a)



Slow Tempo

Attention shifting (P3a)

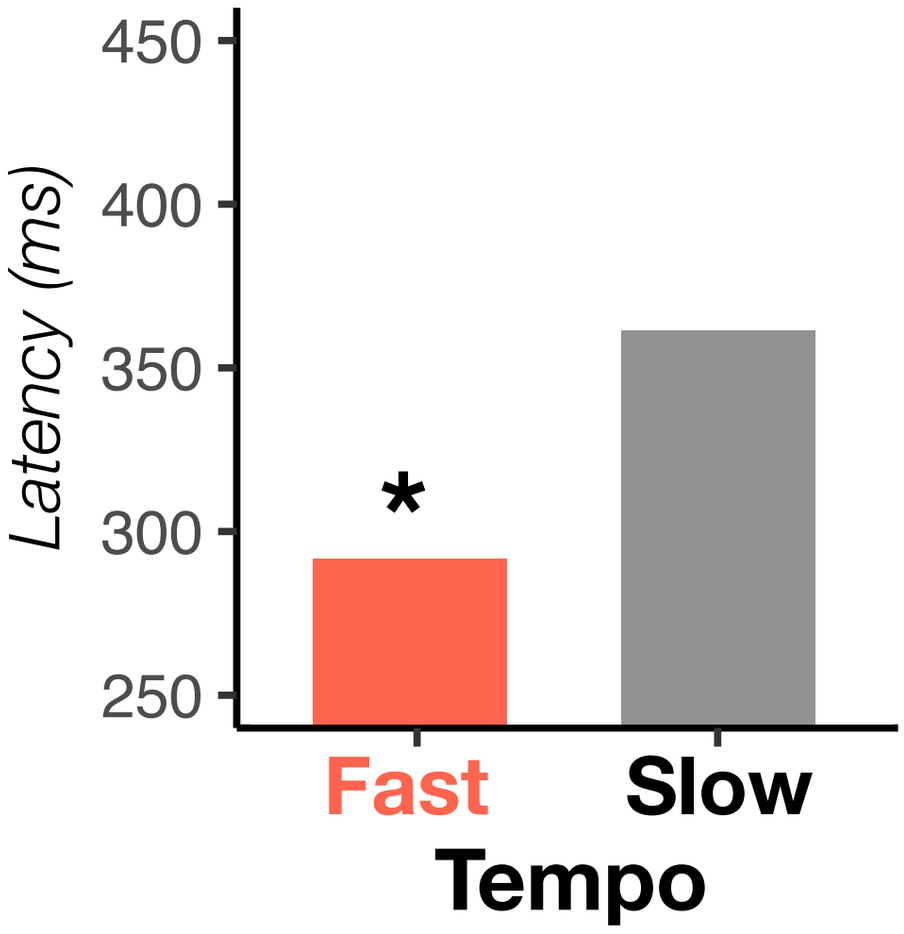


In **slow tempo** condition, **high pitch** has **no influence** on attention

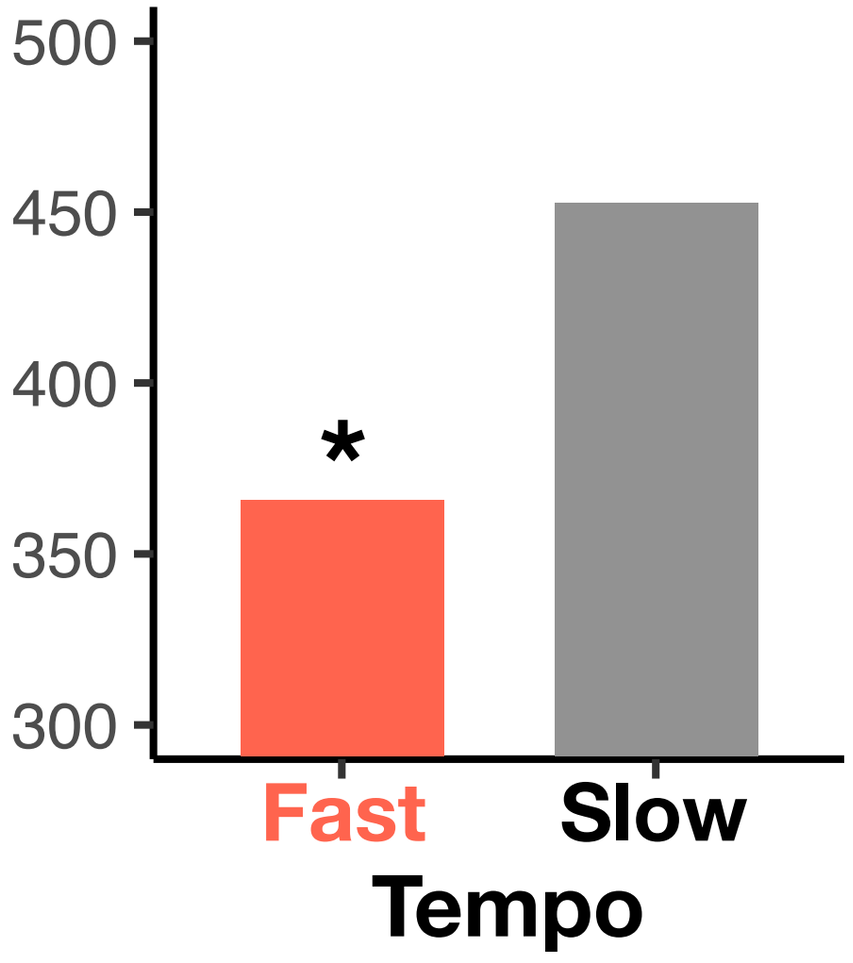
Result

Latency of Cognitive Responses

Auditory Detection (MMN)

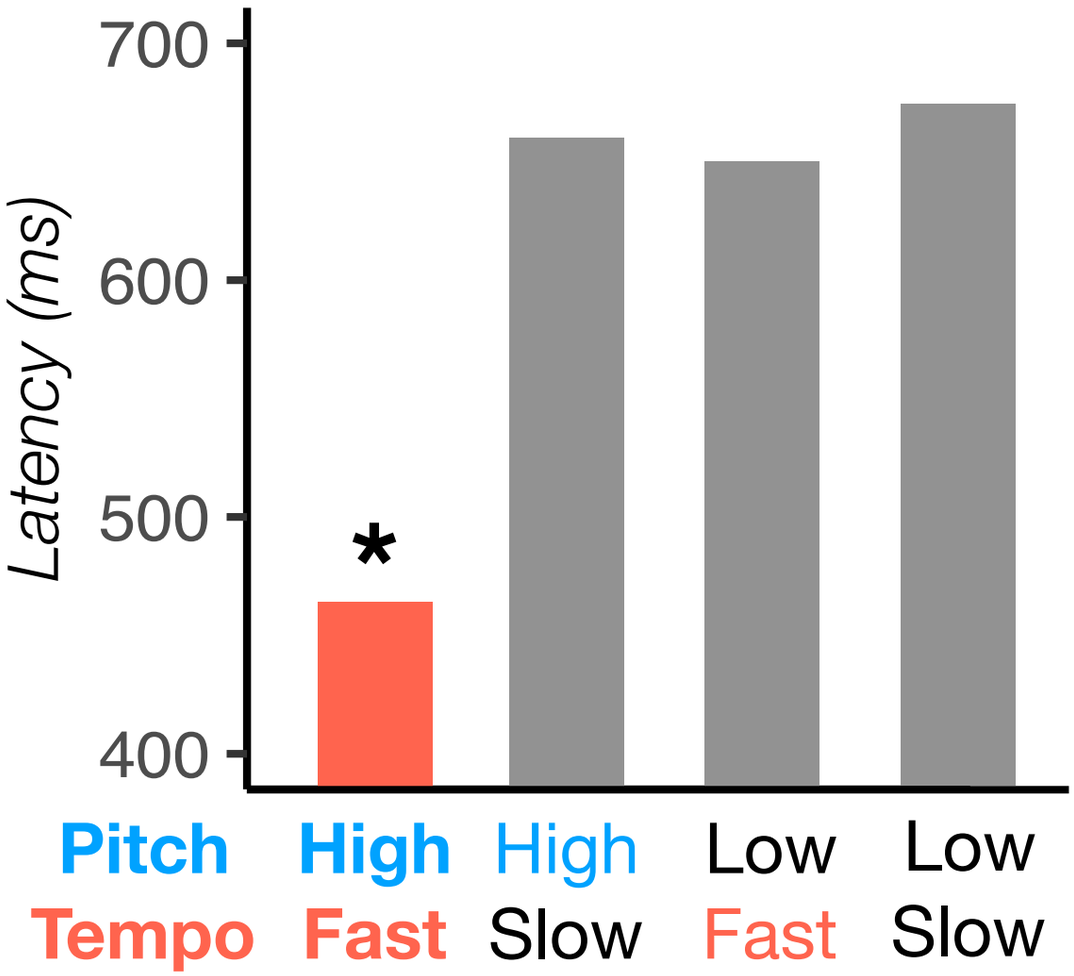


Attention shifting (P3a)

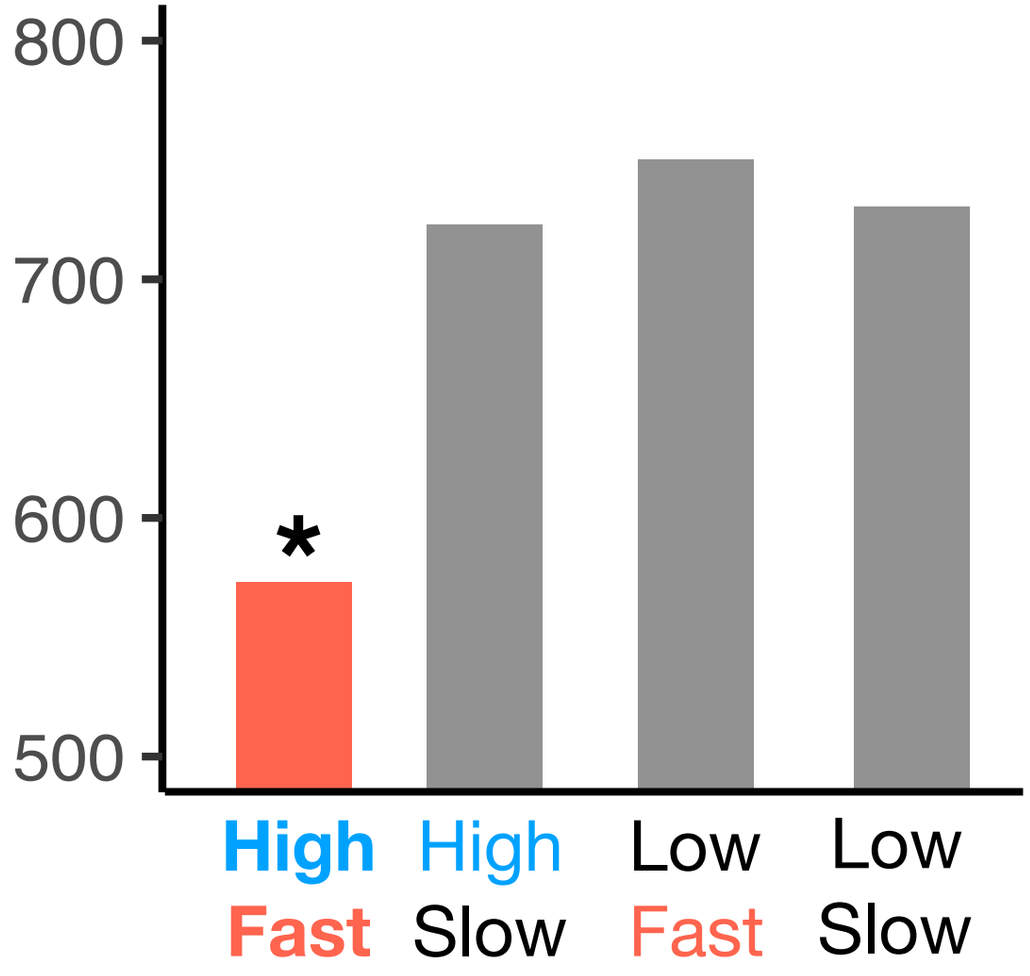


For **simple** melody, **fast tempo** has **shorter** latencies so **quicker** detection & attention-shifting

Auditory Detection (MMN)



Attention shifting (P3a)



For **complex** melody, **pitch** & **tempo** should be **raised together** to speed up cognitive responses

Large-scale Online Study

Different Users in Different Environments

Online Task

Amazon Mechanical Turk

- 976 participants (498 males; 18-76 years old)

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- Dual-task paradigm
- Watch silent film and answer questions

Q. What is the animal in the film?

- Dog
- Bird
- Cat
- Fish

Online Task

Amazon Mechanical Turk

- 976 participants (498 males; 18-76 years old)
- Dual-task paradigm
- Watch silent film and answer questions
- Respond to notification

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Online Task

Amazon Mechanical Turk

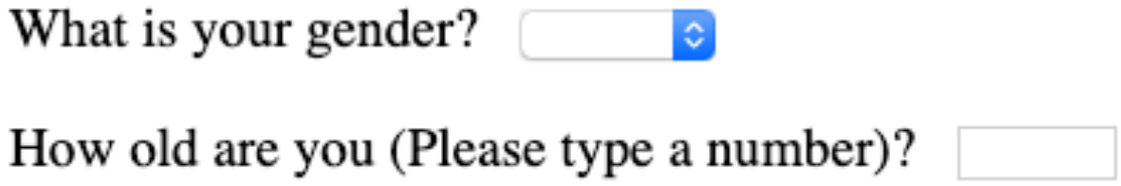
- 976 participants (498 males; 18-76 years old)
- Dual-task paradigm
  - Watch silent film and answer questions
  - Respond to notification
- Reaction time & Hit Rate

Q. What is the animal in the film?

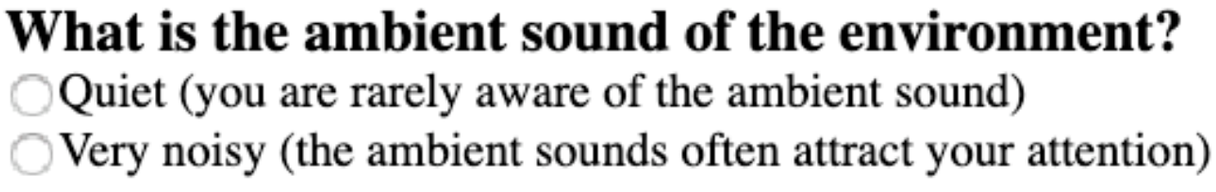
- Dog
- Bird
- Cat
- Fish

Self-report Survey

- User-specific factors (age, gender, & usage frequency)



- Environmental factors (private or public; quiet or noisy)



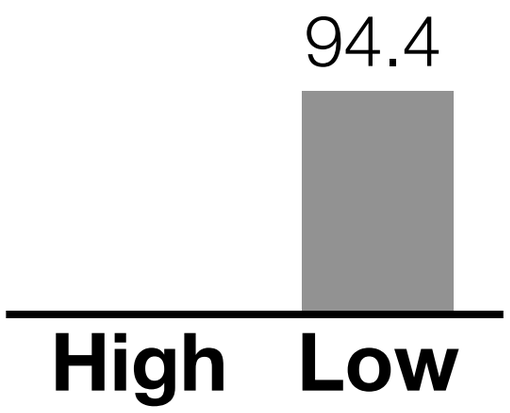
Results

User-specific & Environmental Factors

Low Pitch

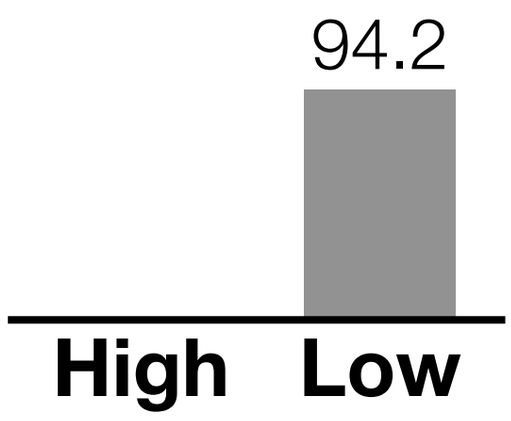
Adults
age: 20-50

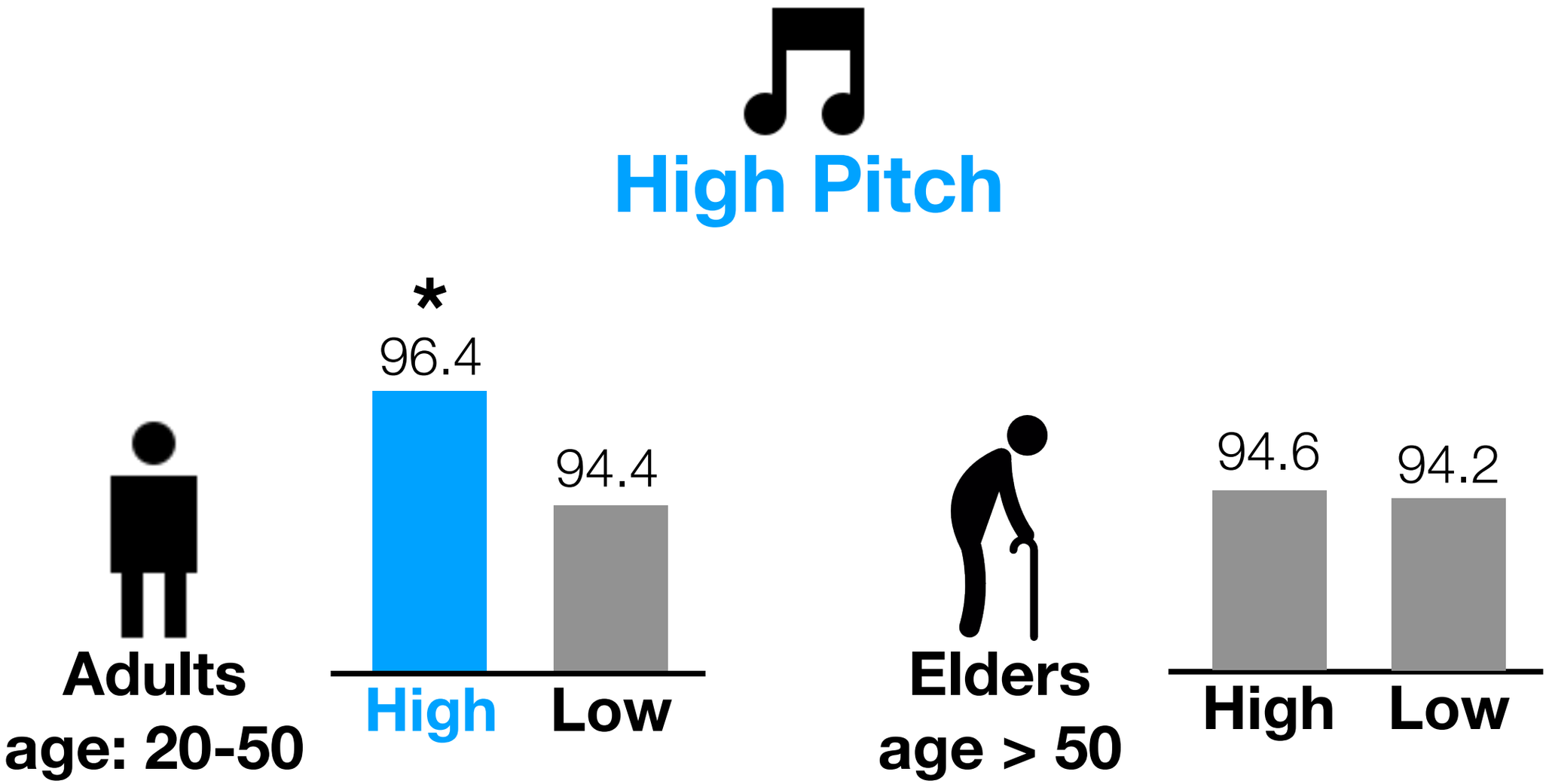
Hit Rate (%)



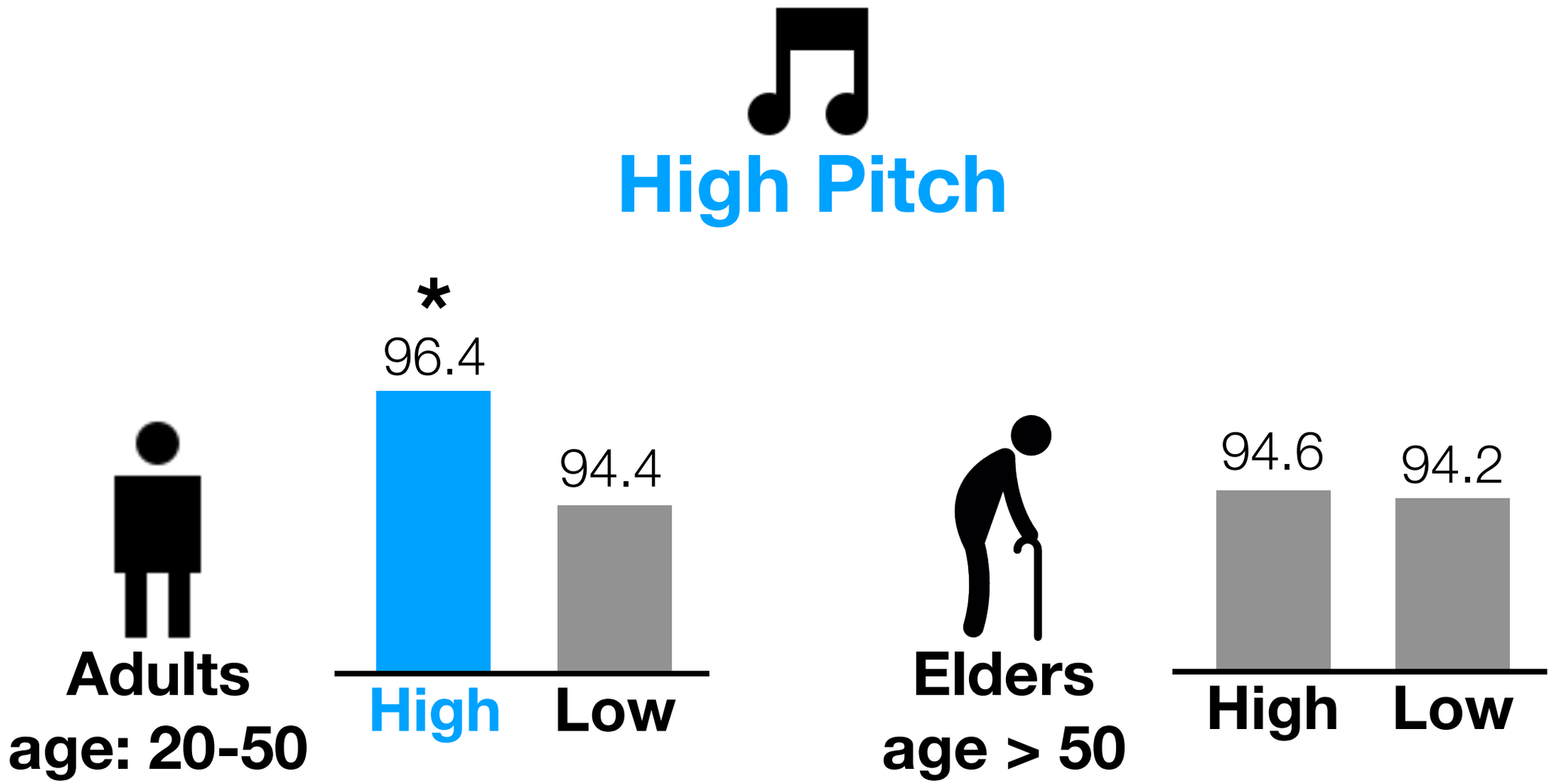
Elders
age > 50

Hit Rate (%)





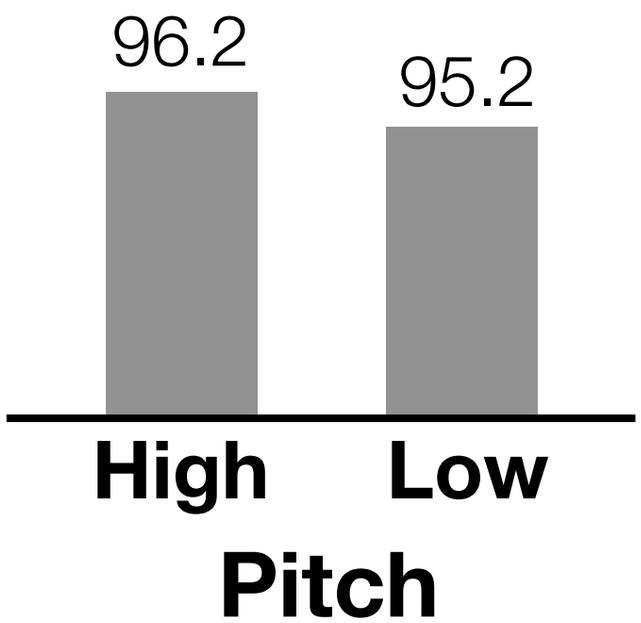
High pitch didn’t increase elders’ hit rate



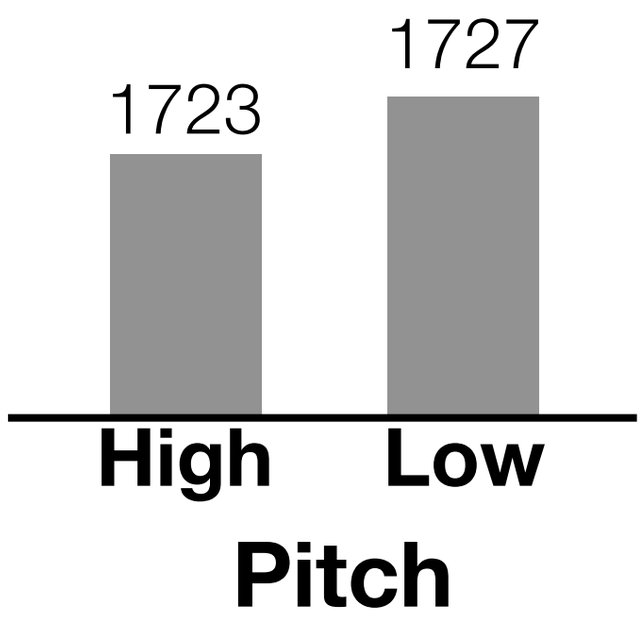
Elders might require **greater changes** in **pitch** to increase hit rate

[Ghosh, 2015; Baldwin, 2016]

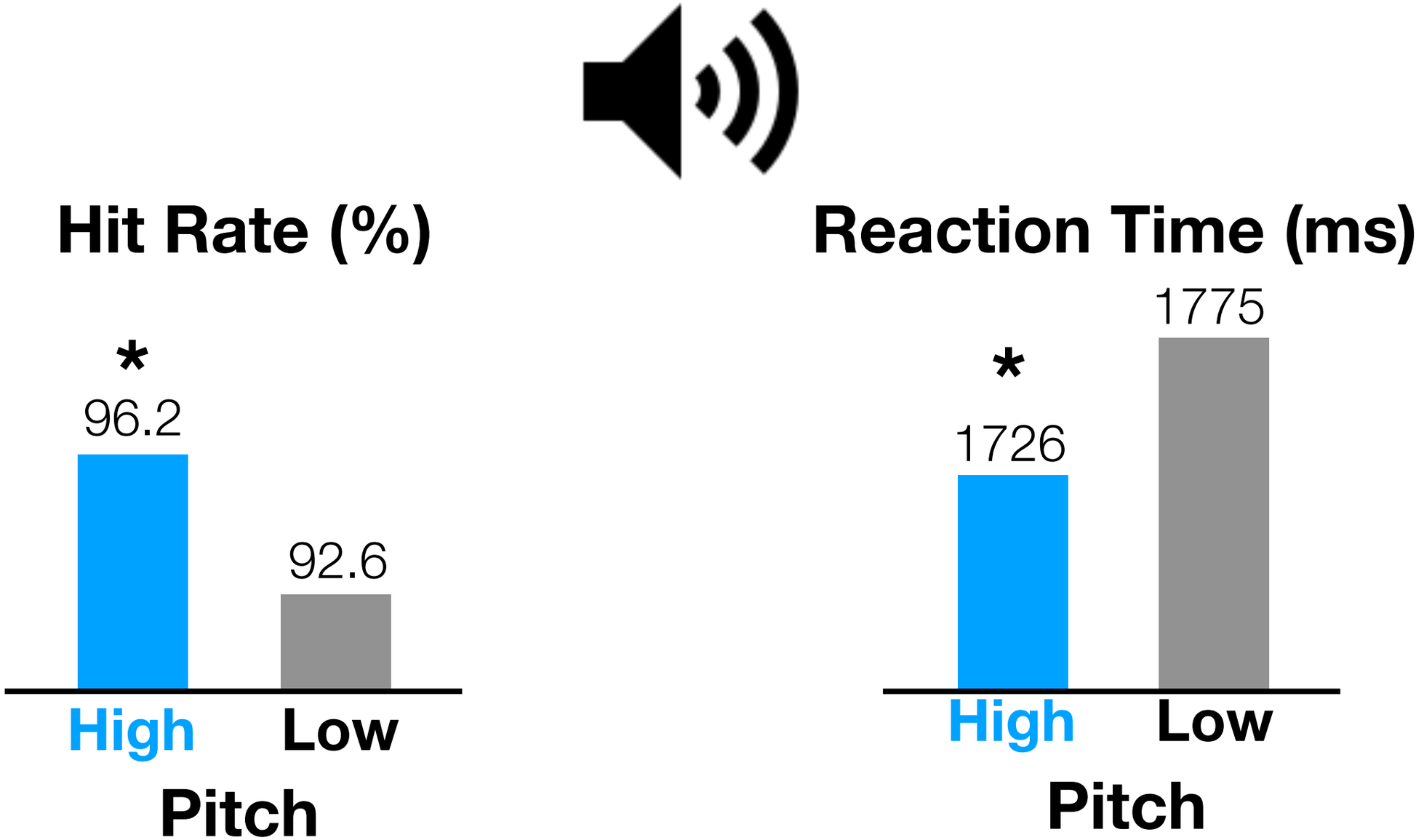
Hit Rate (%)



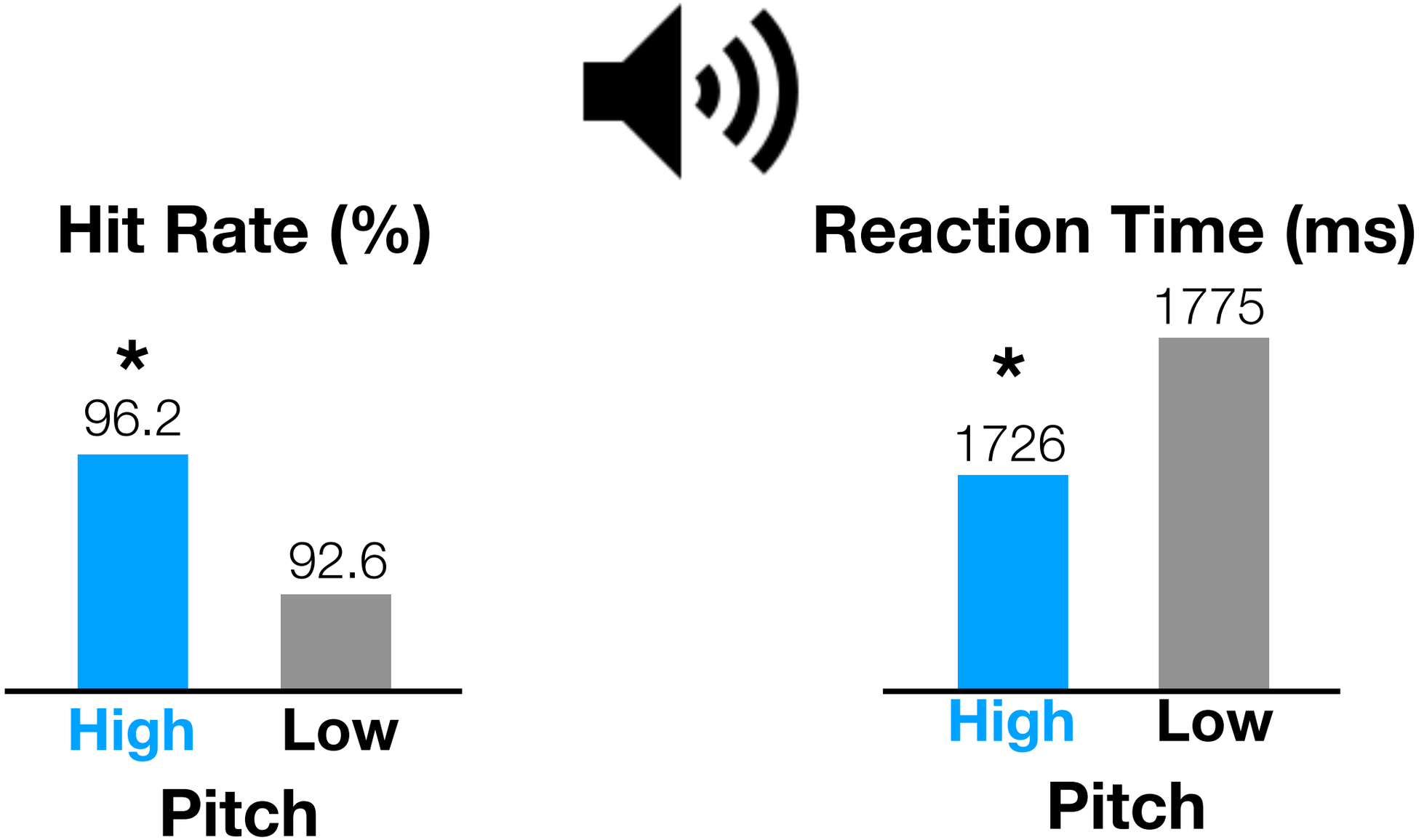
Reaction Time (ms)



In **quiet** place, **pitch** has **no influence** on hit rate and reaction time



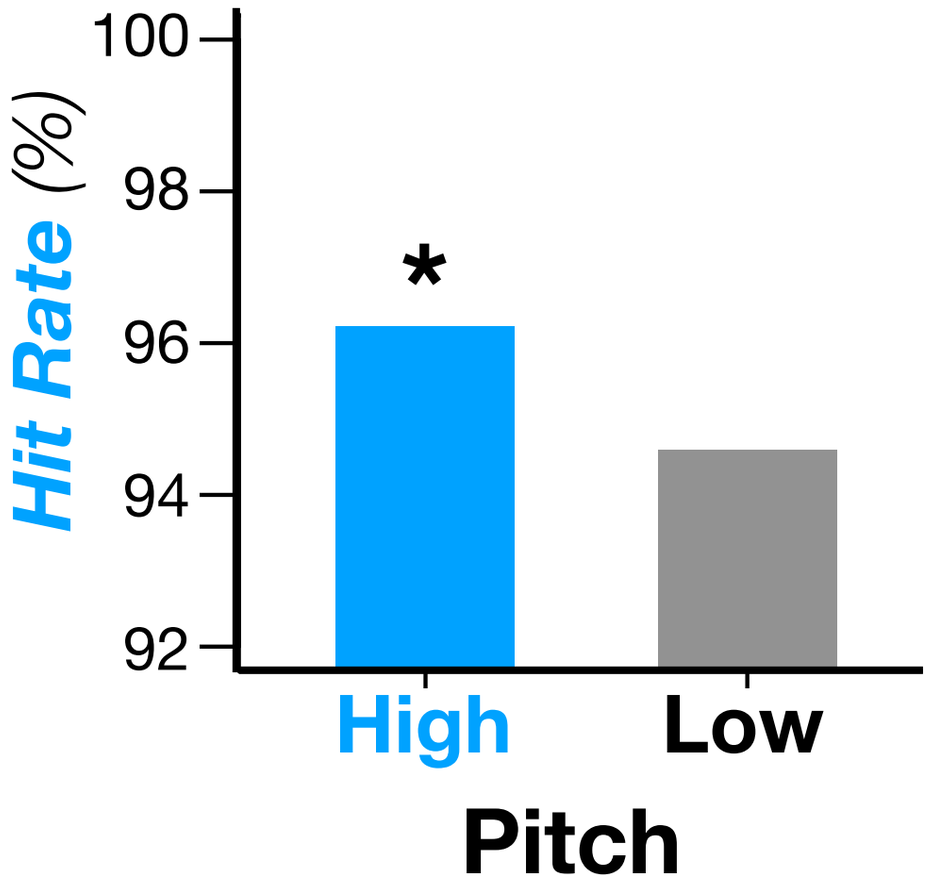
In **noisy** place, **high pitch** has **higher** hit rate and **shorter** reaction time



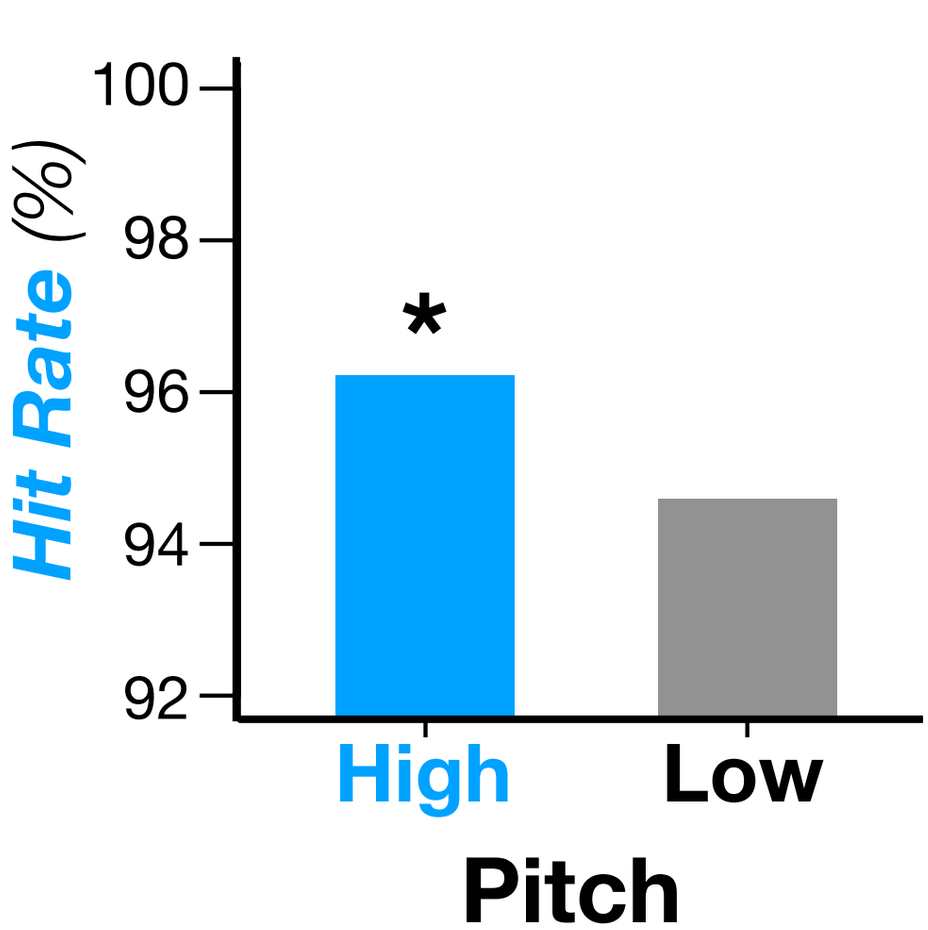
In **noisy** place, **high pitch** is more **distinguishable** than low pitch

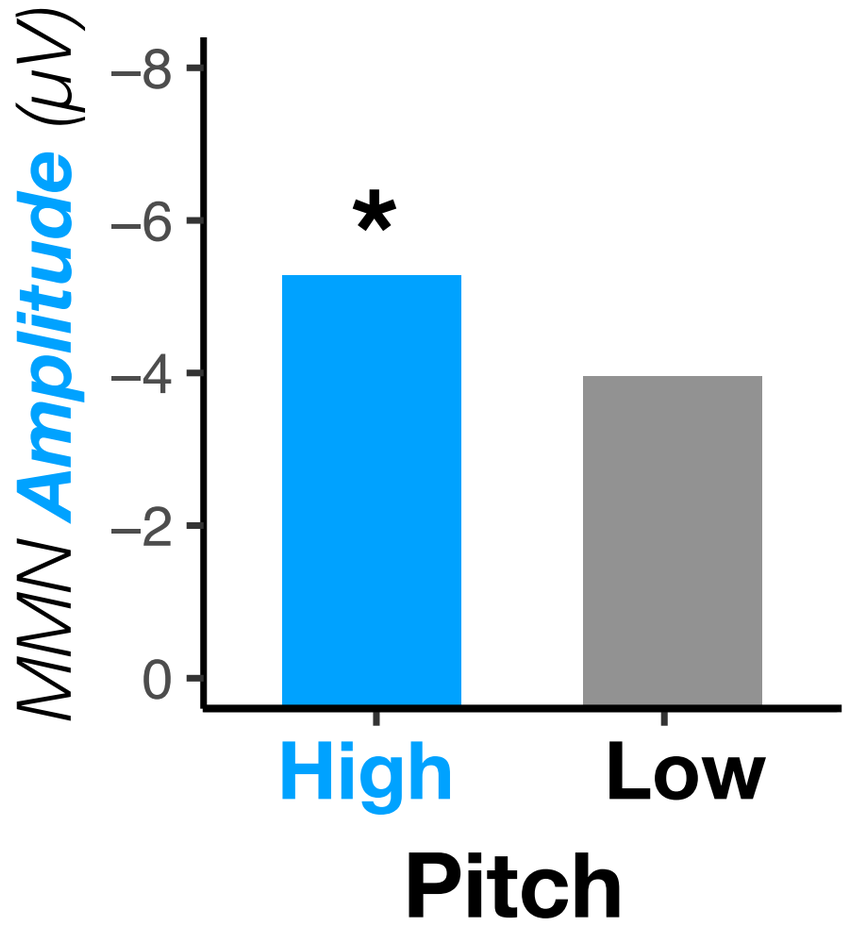
Compare Results

from EEG & Large-scale Online Study



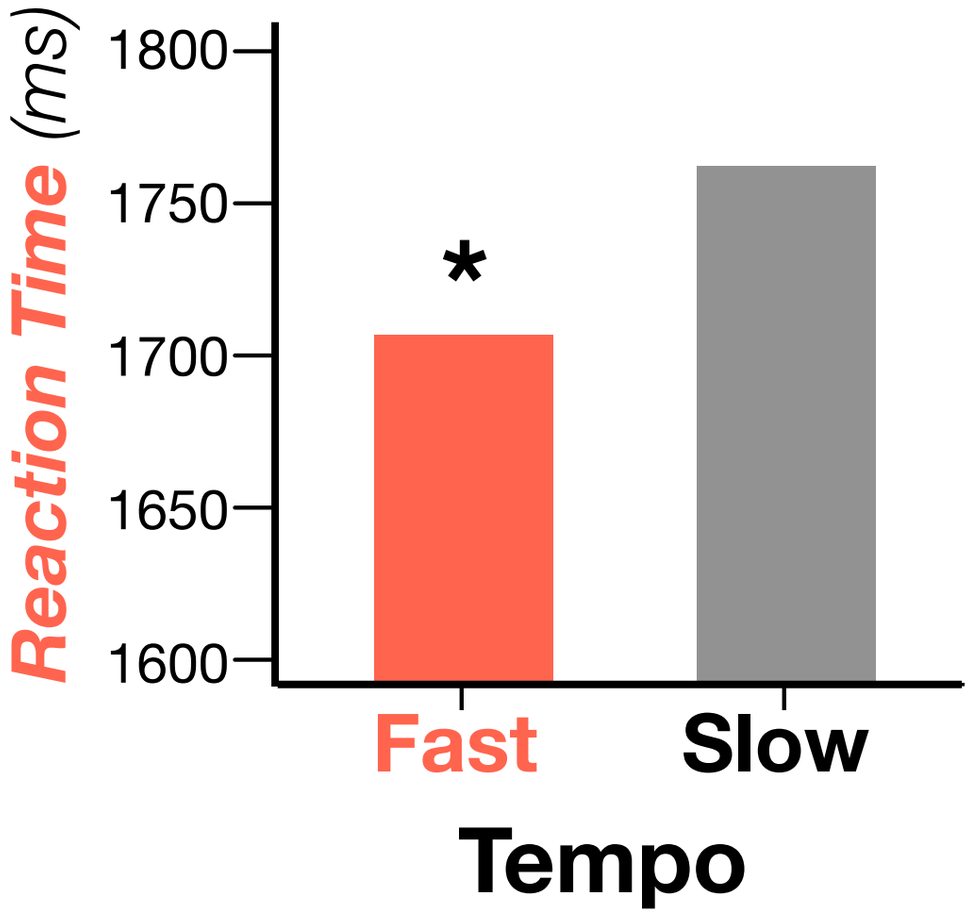
High pitch has **higher** hit rate



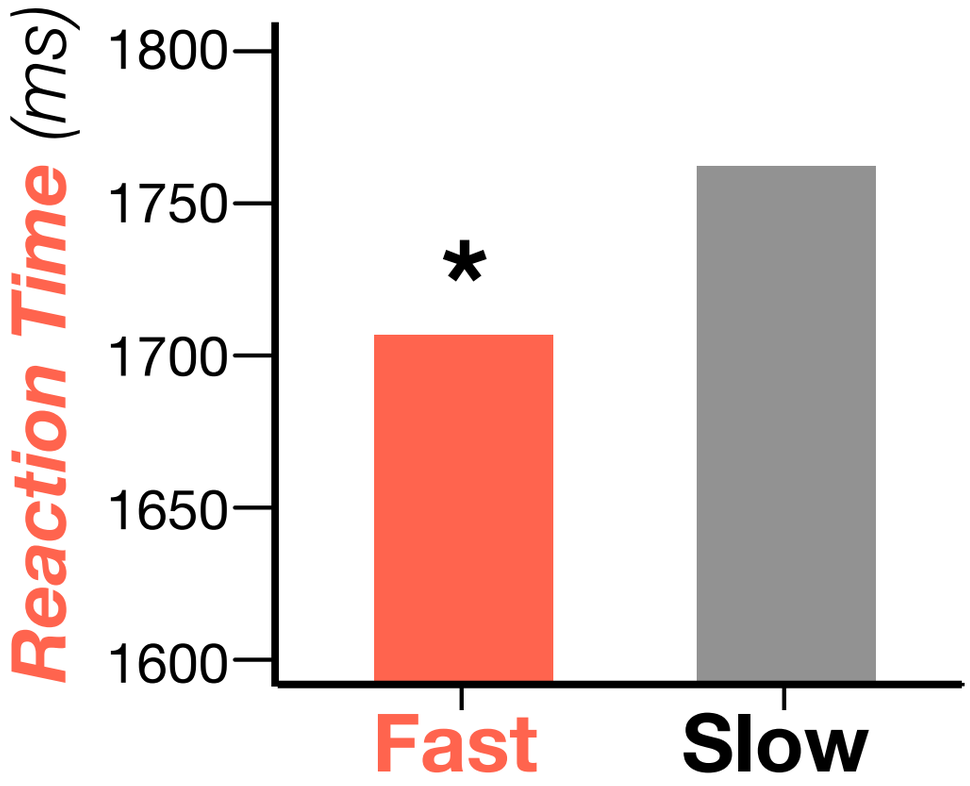


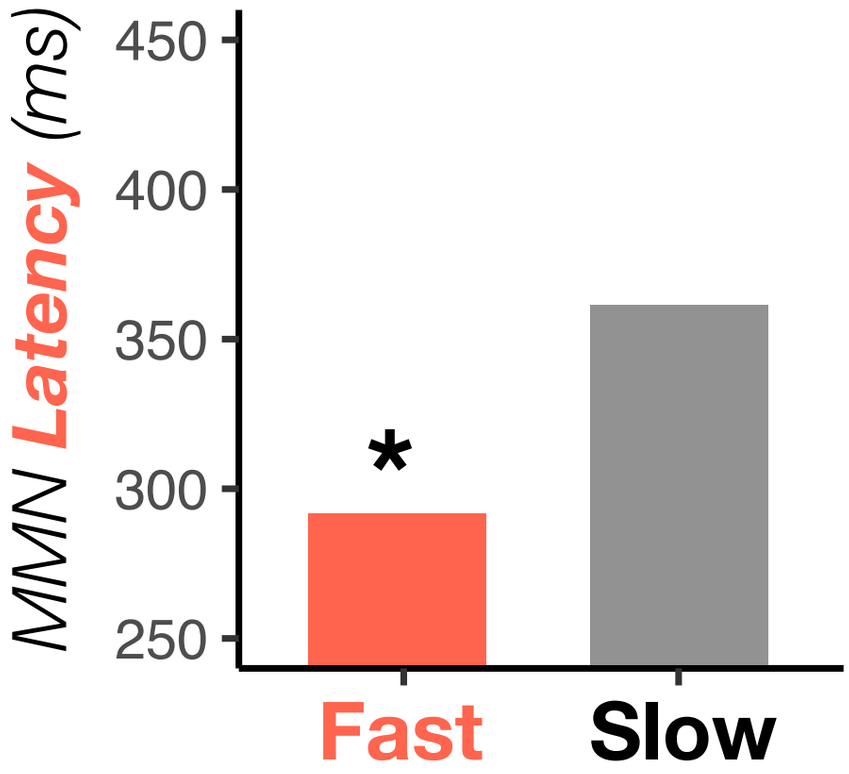
High pitch; **strong** cognitive responses; **high** hit rate

[Näätänen, 2007]



Fast tempo has **shorter** reaction time





Fast tempo; **quick** cognitive responses; **short** reaction time

[Näätänen, 2007]

Comparison Matrix

p<.001
p<.05

		N	Melody	Pitch	Tempo	Melody:Pitch	Melody:Tempo	Pitch:Tempo
Overall		967	**RT (F=156)** Acc. (F=10)	Acc. (F=13)	**RT (F=21)**		**RT (F=22)** Acc. (F=4)	
Age	Adult	832	**RT (F=132)** Acc. (F=8)	**Acc. (F=15)**	**RT (F=17)**		**RT (F=20)**	Acc. (F=4)
	Elder	121	**RT (F=25)**		RT (F=4)			
Gender	Female	478	**RT (F=77)** Acc. (F=5)		RT (F=15)		RT (F=10) Acc. (F=4)	
	Male	489	**RT (F=82)** Acc. (F=5)	Acc. (F=13)	RT (F=7)		RT (F=20)	
Place	Private	885	**RT (F=138)** Acc. (F=15)	Acc. (F=7)	**RT (F=20)**		**RT (F=19)** Acc. (F=4)	
	Public	82	**RT (F=19)**	Acc. (F=9)			RT (F=4)	
Ambient Sound	Quiet	690	**RT (F=99)** Acc. (F=8)		**RT (F=16)**		**RT (F=15)**	
	Noisy	277	**RT (F=59)**	RT (F=4) Acc. (F=14)	RT (F=5)	Acc. (F=7)	RT (F=7)	
Using Audio Notifications	Often	367	**RT (F=56)** Acc. (F=5)		RT (F=7)		RT (F=10)	
	Sometimes	438	**RT (F=77)**	Acc. (F=12)	RT (F=10)		RT (F=11)	
	Rarely	162	**RT (F=26)**					

Effects of Musical Parameters on Users' Responses

- **Pitch:** cognitive **strength**, thereby **hit rate**
- **Tempo:** cognitive **speed**, thereby **reaction time**
- **Melody** is a compound parameter; change **shape** of EEG waveform

The Effects Change across Different Users & Environments

- **Elders** might need **larger changes** in **pitch** to increase hit rate

- **High pitch** is more beneficial to hit rate & reaction time in **noisy** place

Acknowledgement

Anonymous Reviewers

For insightful comments

Professor Chin-Teng Lin

Former director of Brain Research Center

Taiwan Ministry of Science and Technology (MOST)

104-2628-E-009-001-MY3, 105-2221-E-009-095-MY3, and 107-2218-E-009-053-.

Backup

Self-report Survey

- User-specific factors (age, gender, and usage frequency)

What is your gender?

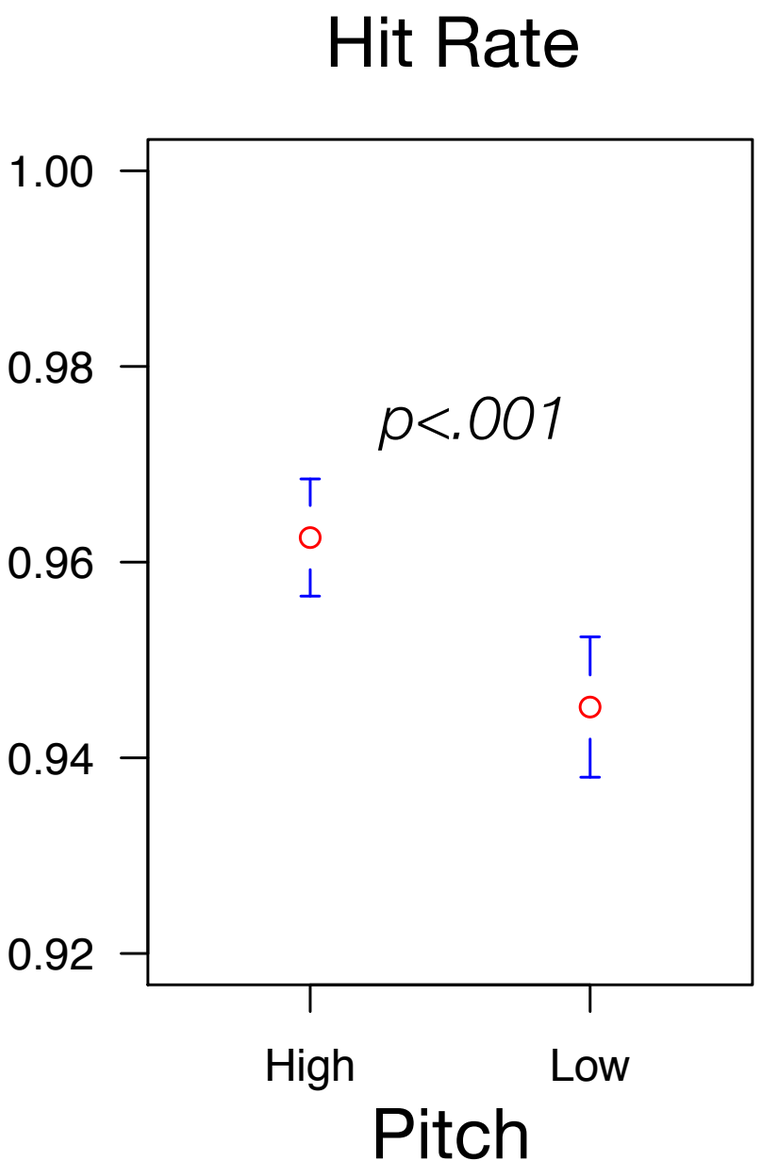
How old are you (Please type a number)?

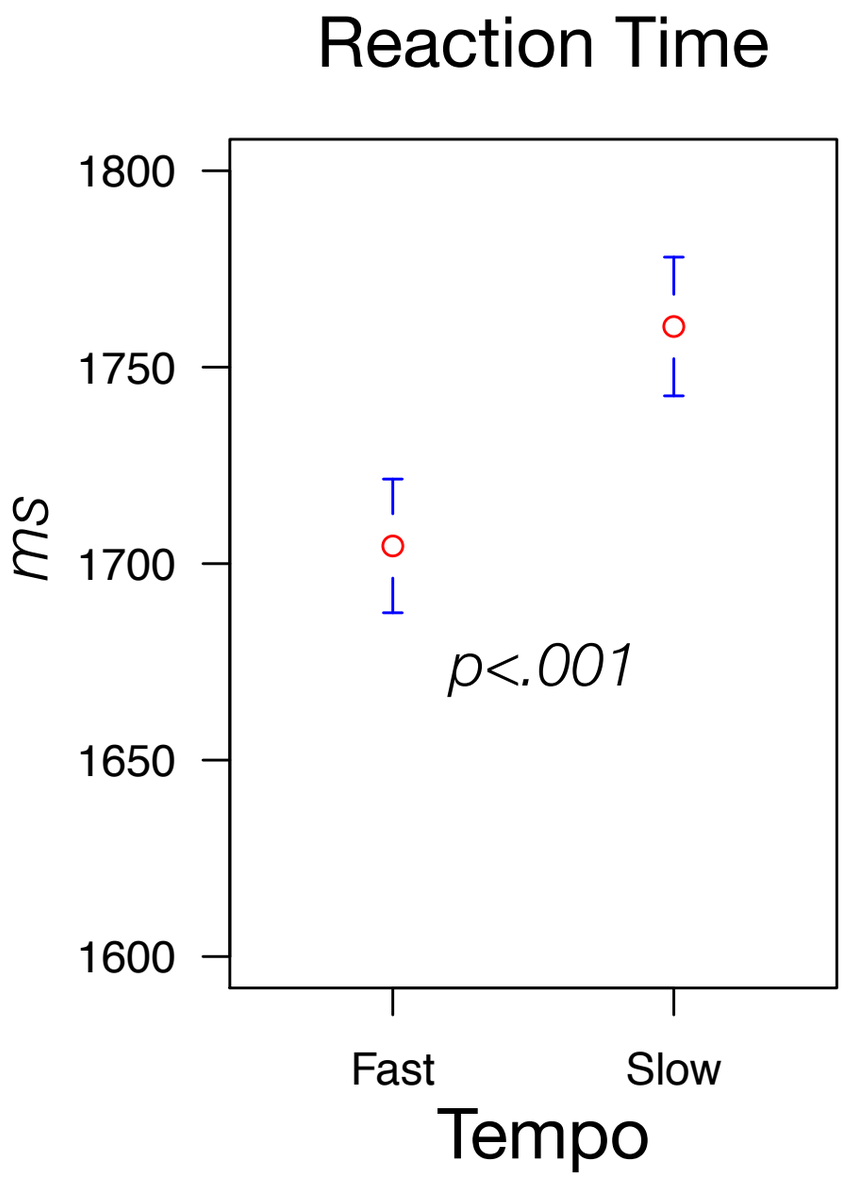
Experience of Using Auditory Notifications:
- ○ I often turn on the auditory notifications of my devices
- ○ I sometimes turn on the auditory notifications of my devices
- ○ I often turn off the auditory notifications of my devices

- Environmental factors (private or public; quiet or noisy)

What kind of environments that you are in now?
- ○ Public space (e.g., roads, public squares or parks)
- ○ Private space (e.g., your bedroom, living room or personal office)

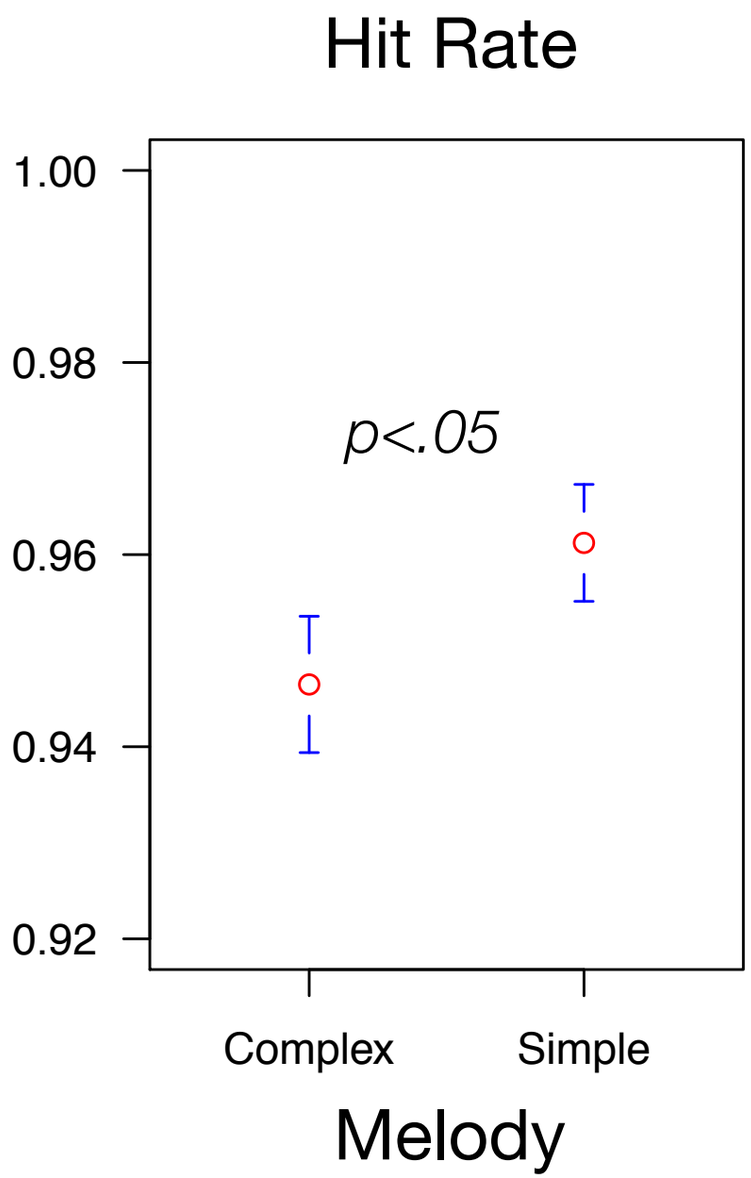
What is the ambient sound of the environment?
- ○ Quiet (you are rarely aware of the ambient sound)
- ○ Very noisy (the ambient sounds often attract your attention)

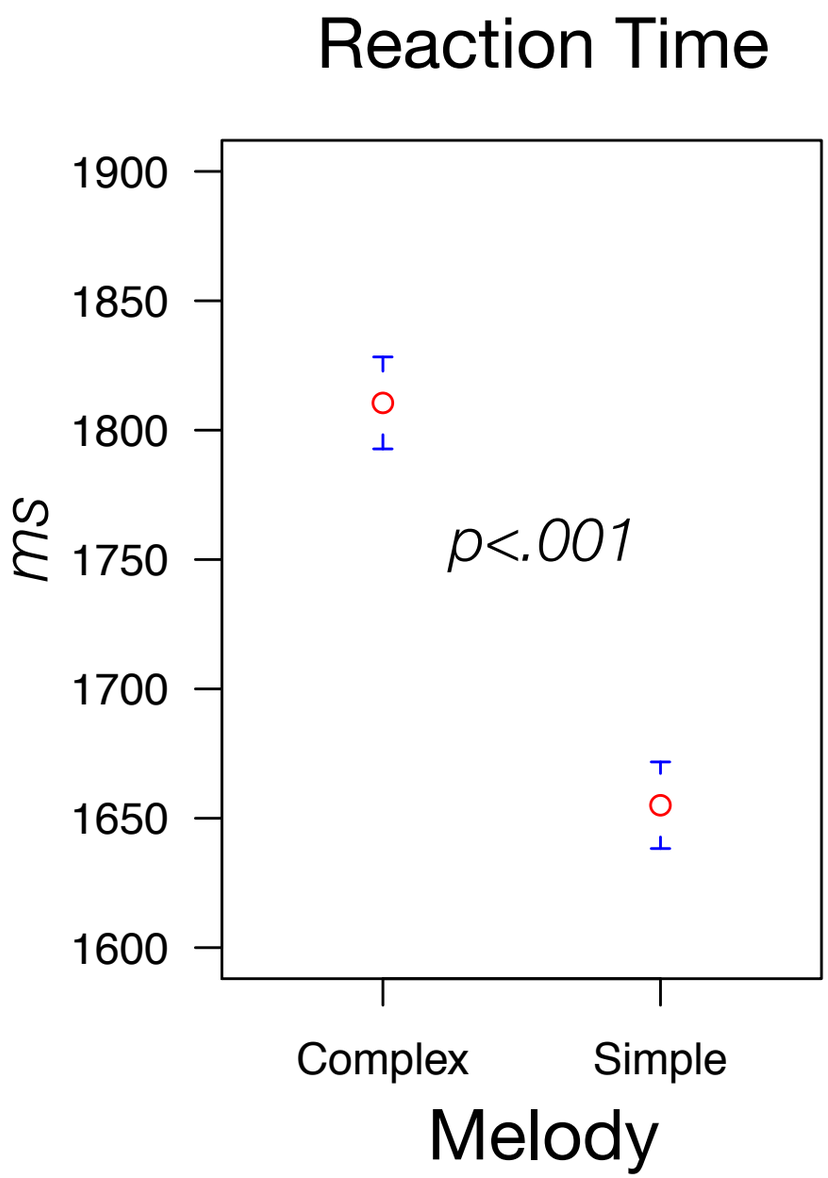




- Pitch related to how strongly cognitive responses are evoked, linked to hit rate
- Tempo related to how fast they react to it, linked to reaction time

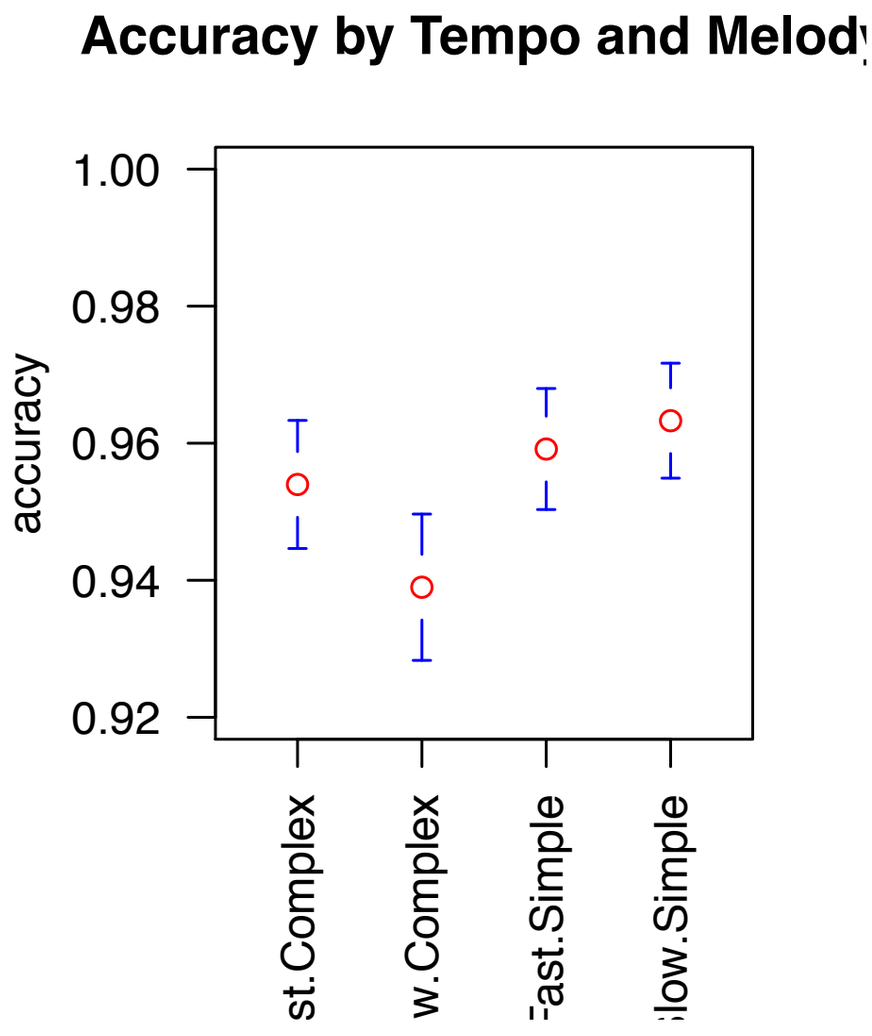
[Näätänen, 2007]



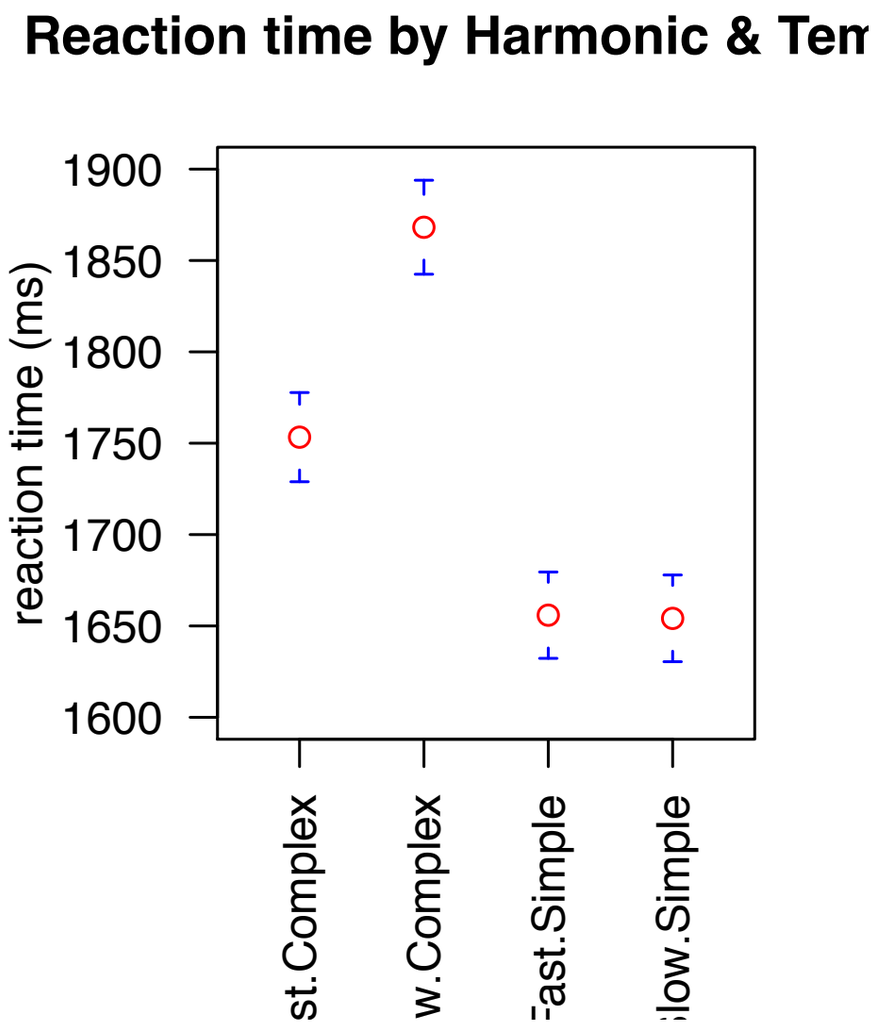


Complex-melody notifications have longer reaction time but lower hit rate

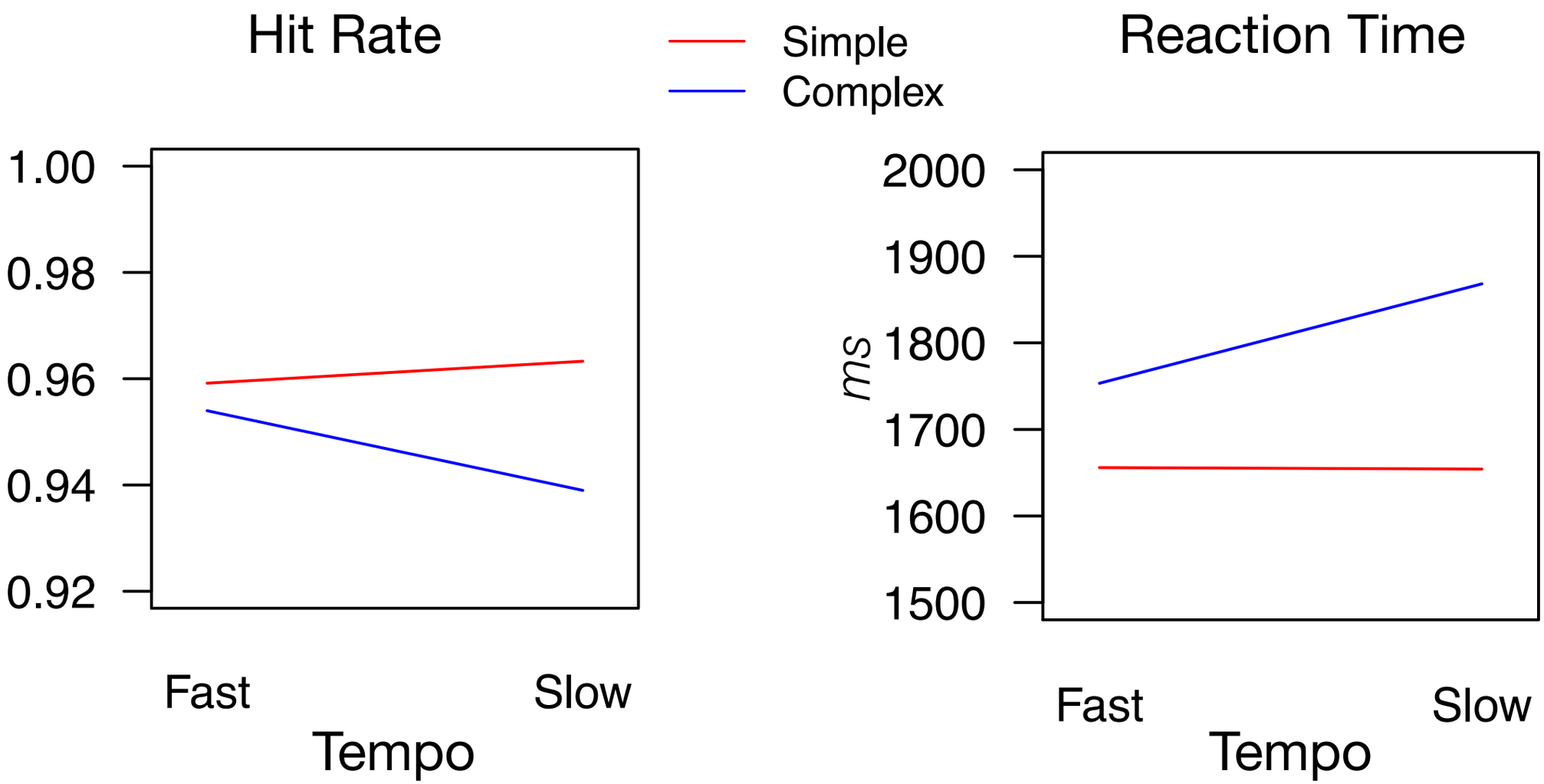
Hit Rate



Reaction Time

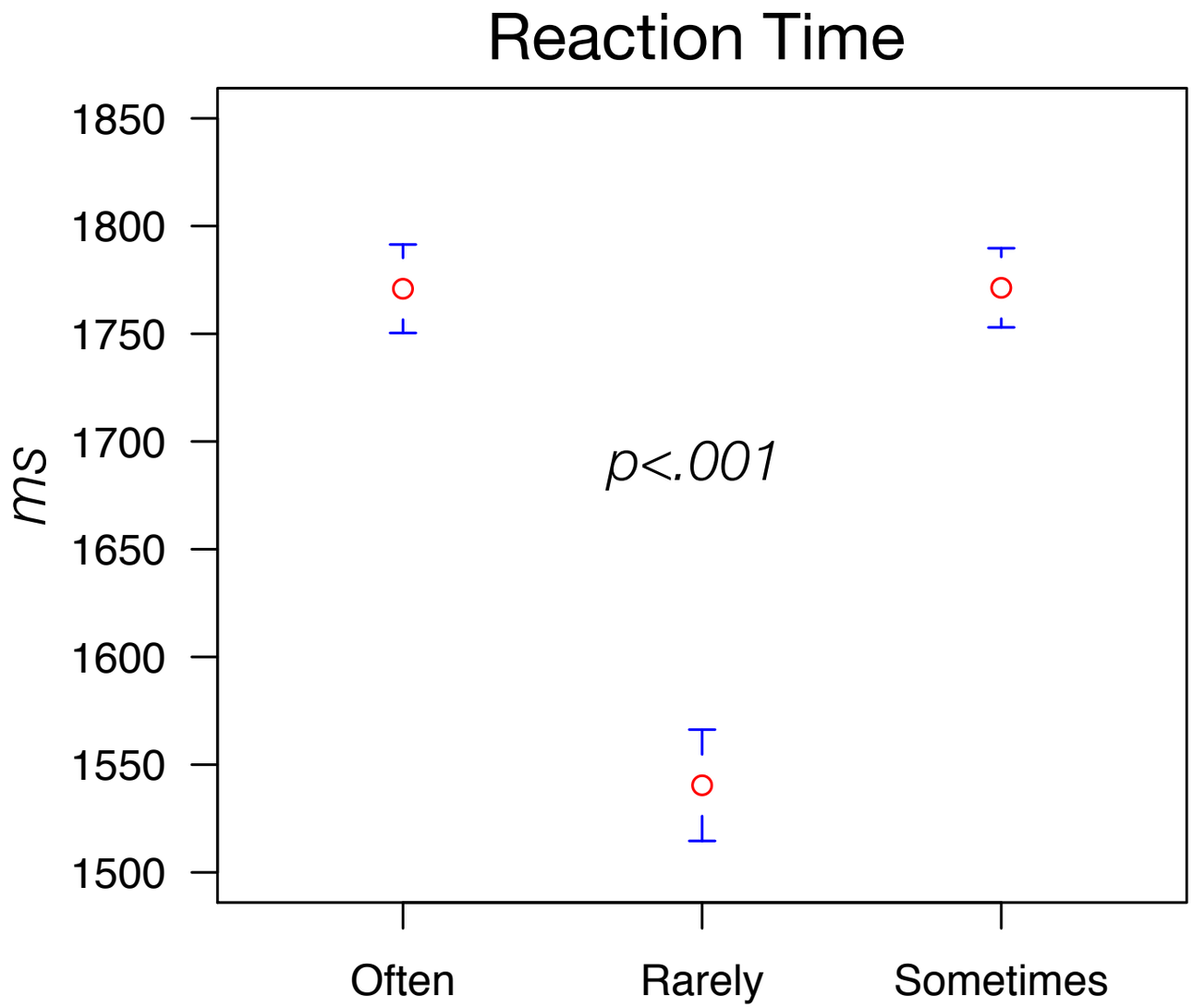


Interaction effects between melody and tempo on reaction time and hit rate



Melody affect hit rate, reaction time, and effect of tempo

Using Audio Notification



Rarely group experienced novelty effect on reacting to audio notifications