Self-Motion Processing in Humans from Psychophysics to High Density Electrical Mapping

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Talk Overview

- Passive Heading detection
  1. Cue Conflict
  2. Neural correlates of heading detection change

- Active tasks
  3. Feasibility of neural recordings while walking
  4. Cognitive flexibility while walking in young and old

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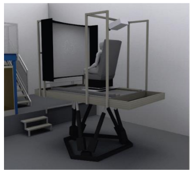
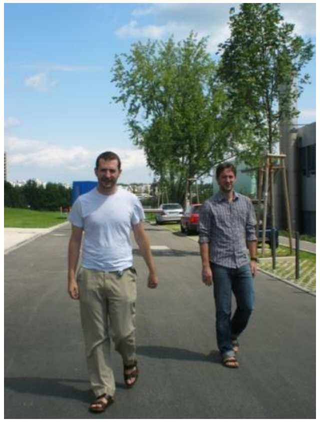


Self-motion

- Self-motion
  - Walking
  - Driving
- Cues for Self-motion
  - Visual
  - Vestibular
  - Somatosensory
  - Etc.



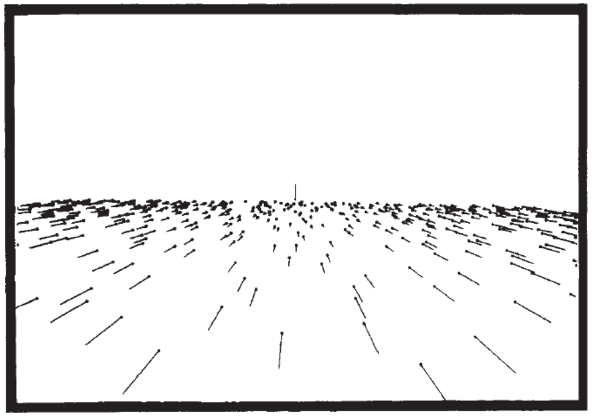
Inertial (vestibular)

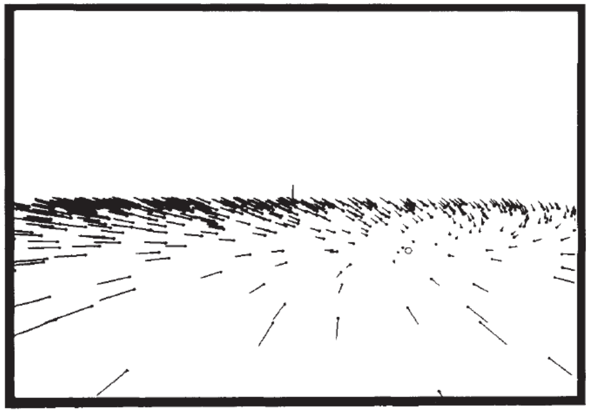
- Otholiths
  - Linear acceleration
- Semi-circular Canals
  - Rotational velocity
- Function
  - Eye movements
  - Heading
- Disorders
  - Vertigo
  - Motion sickness
  - Falls

Optic flow

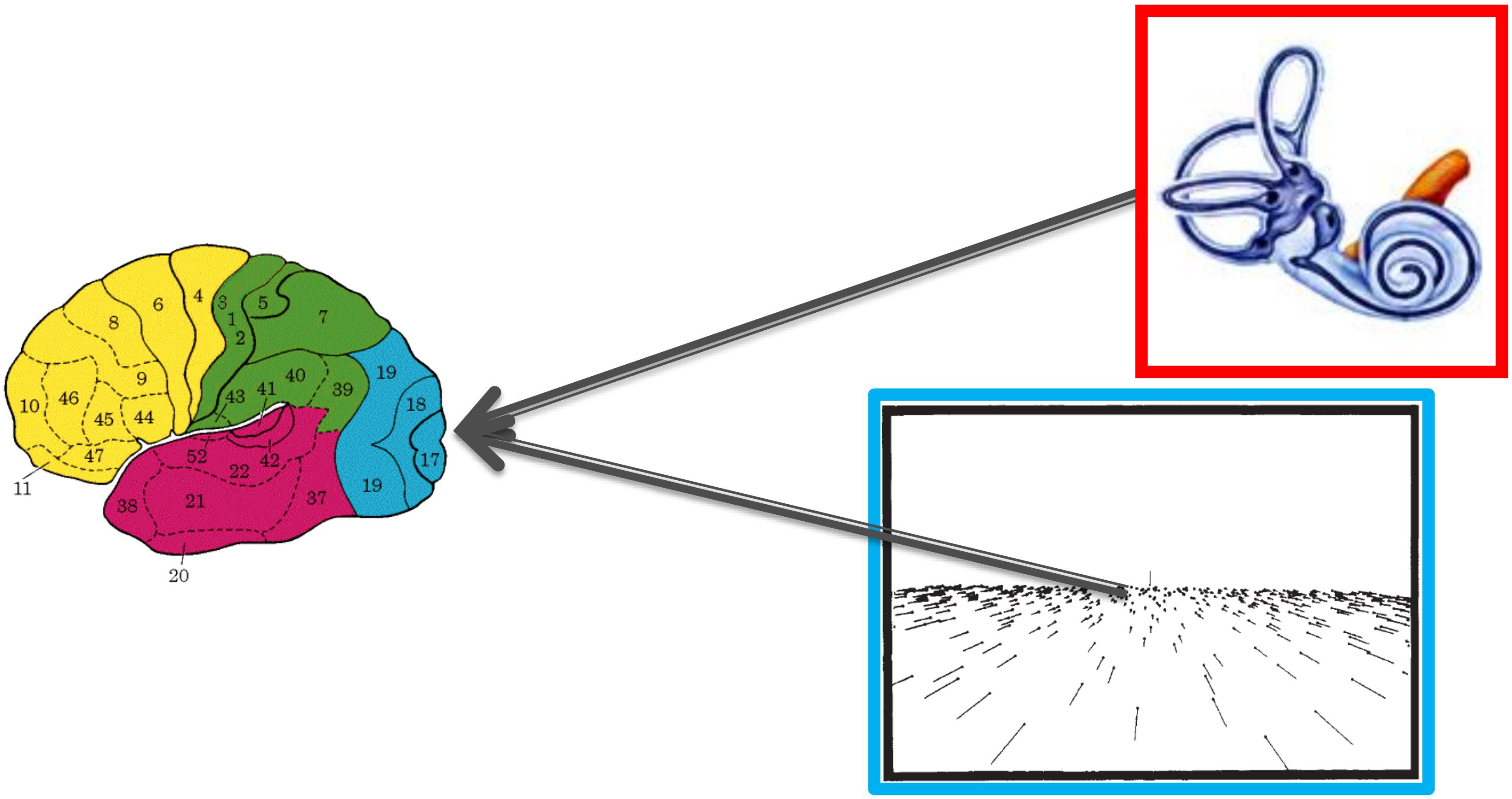
Behavioural
- Relative distance perception
- Heading

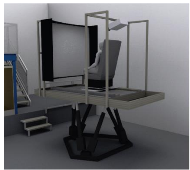
Neurophysiology
- Vection
  - hFMRI (MT+)
- Heading
  - MST



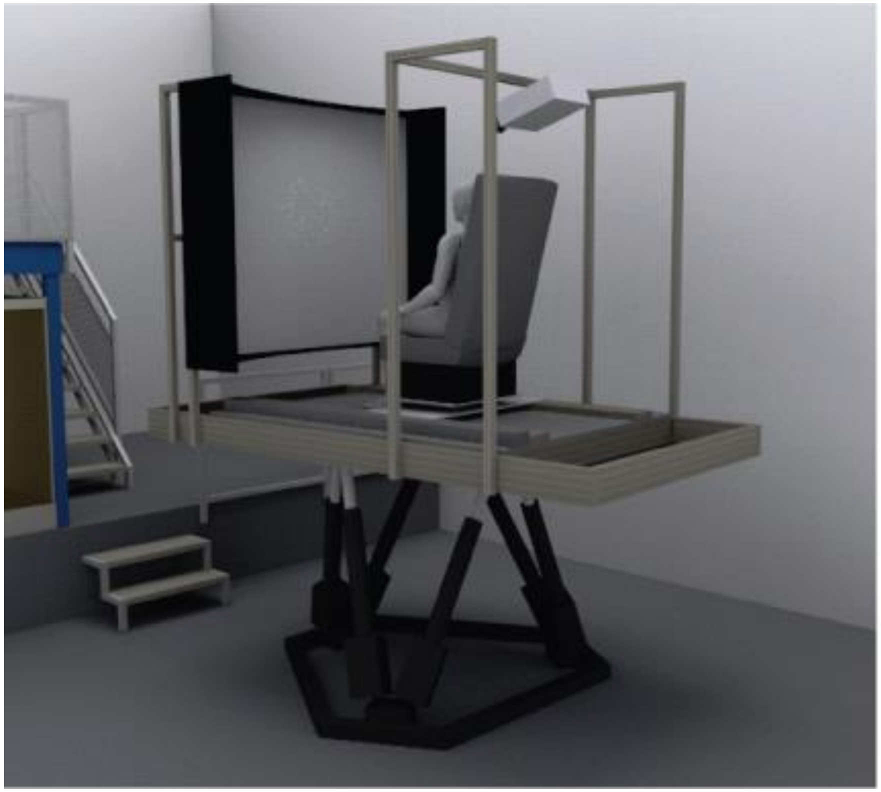


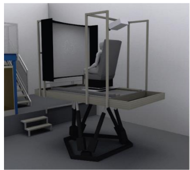
Combination of Senses



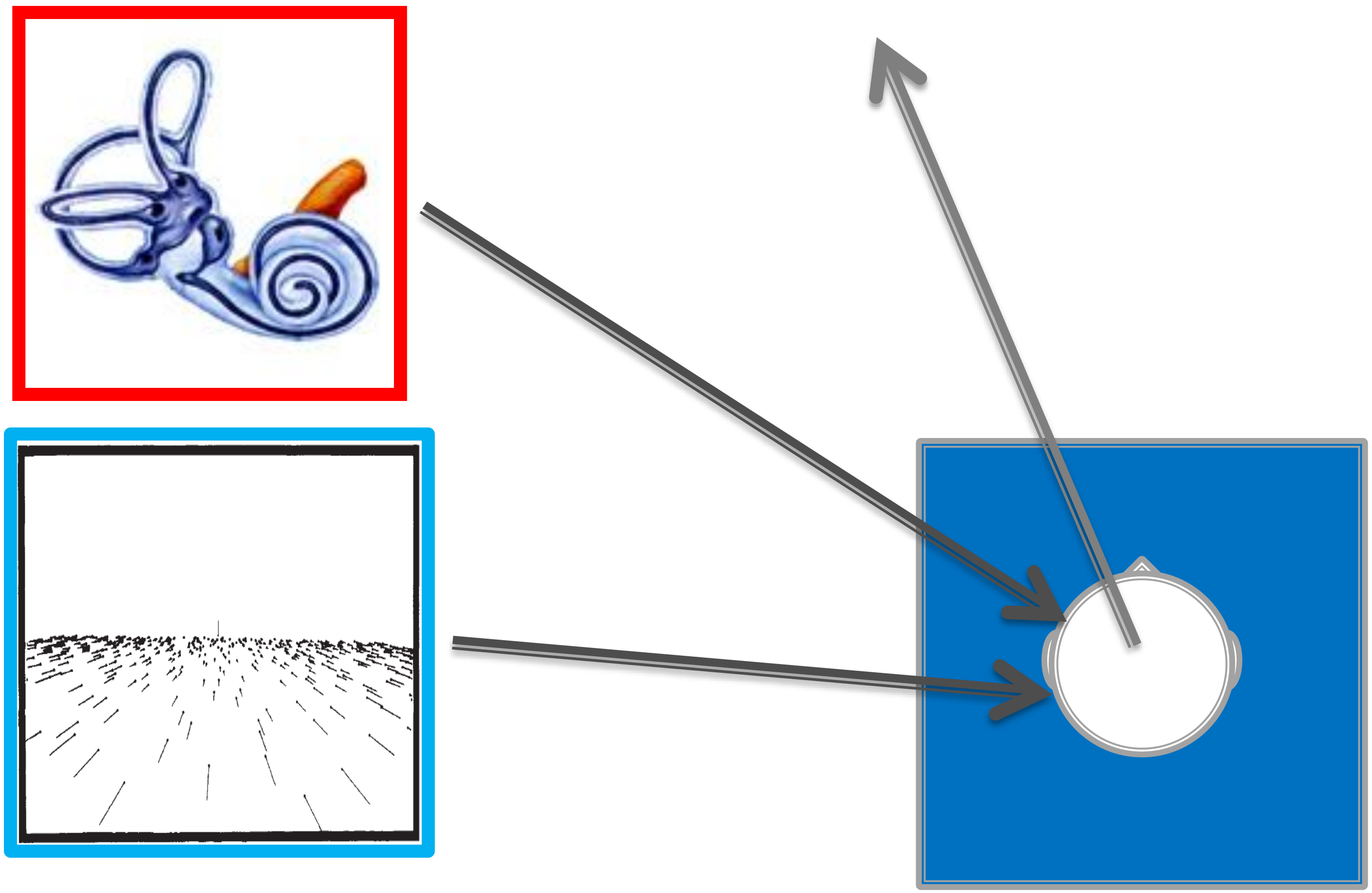


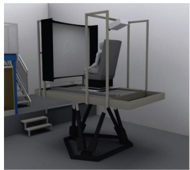
Virtual reality setup and stimuli



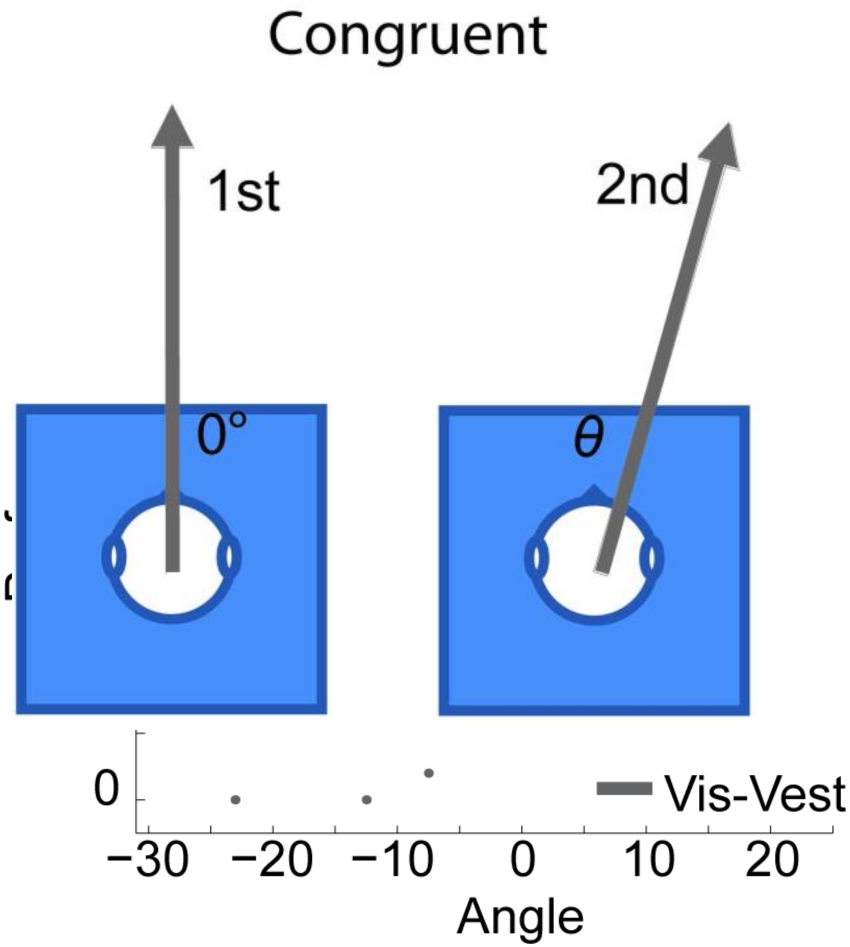


Visual-Vestibular Integration for Heading

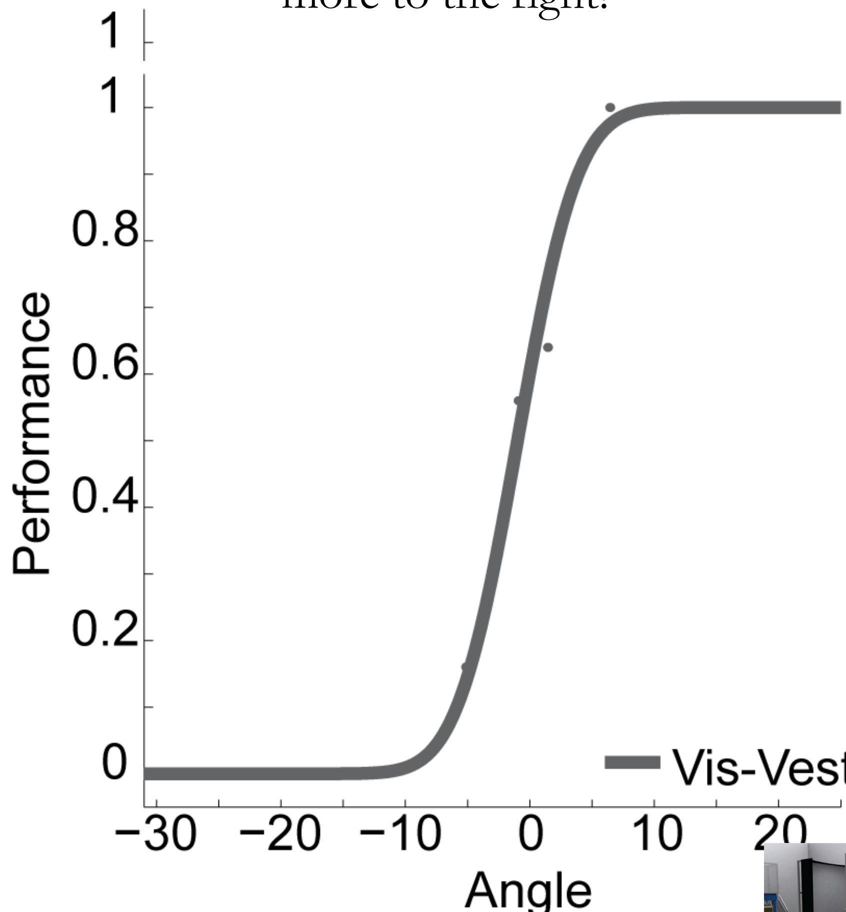


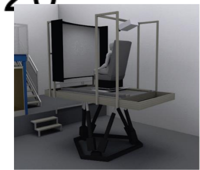


Reliability

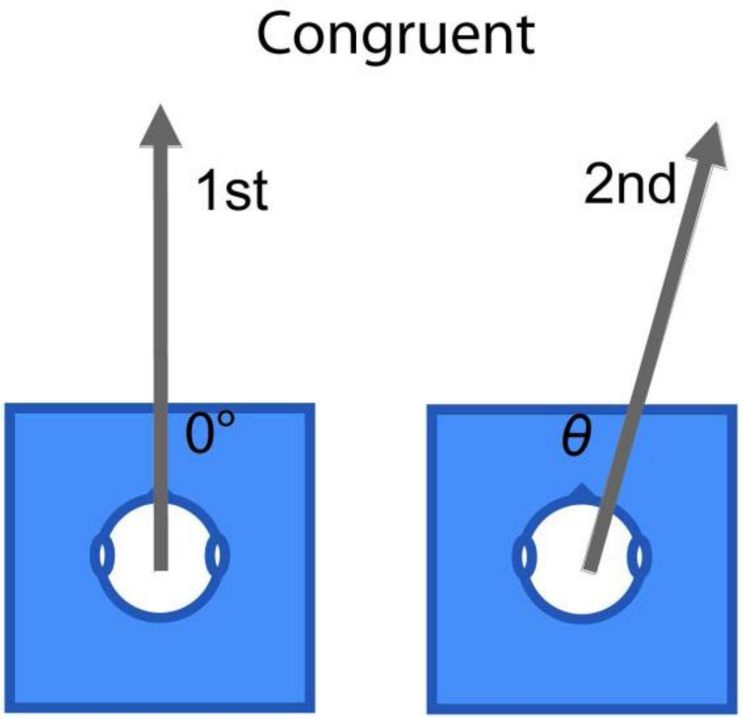


Was the second movement more to the right?



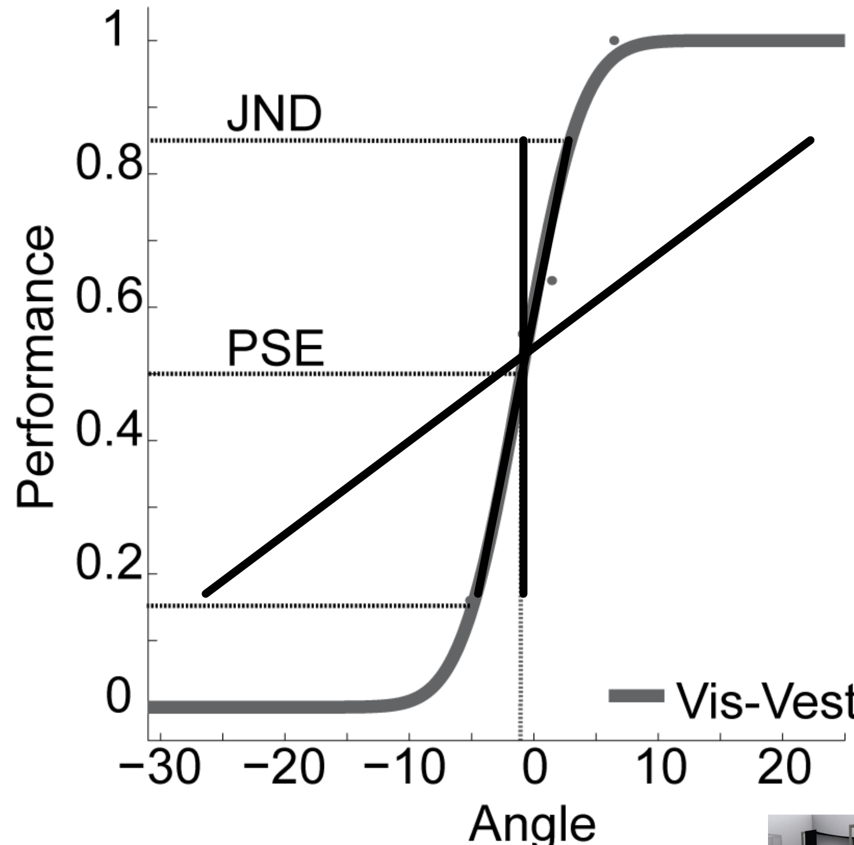


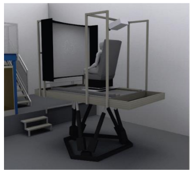
Reliability



Just Noticeable Difference (JND)

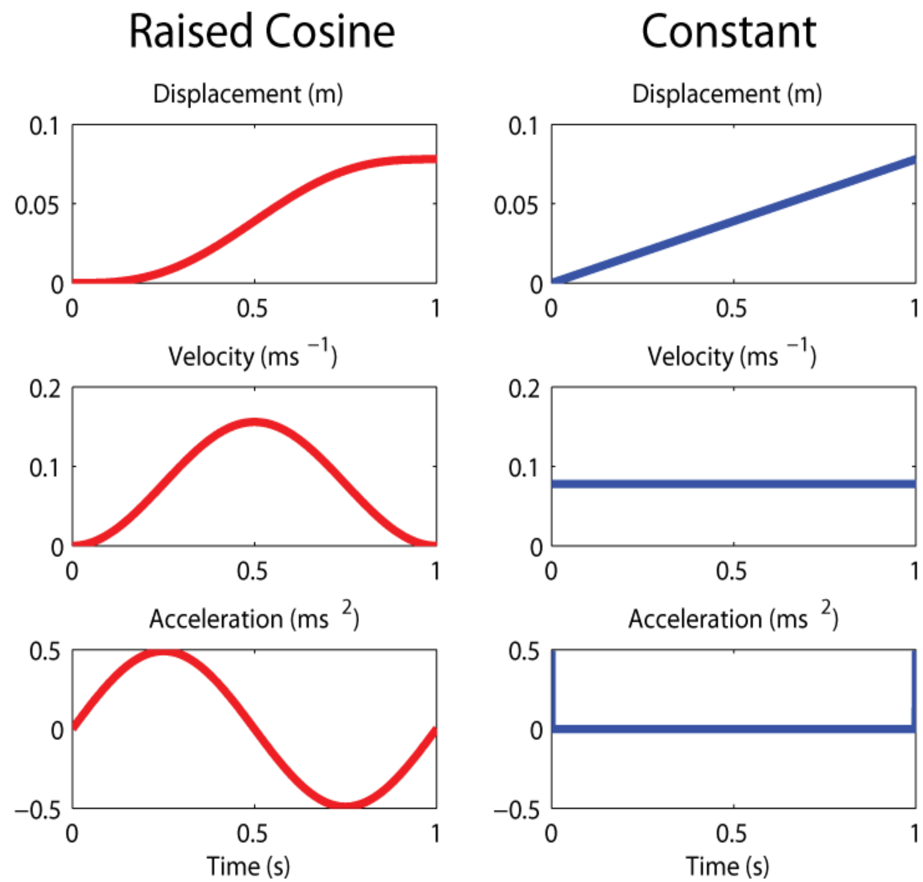
Was the second movement more to the right?

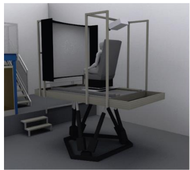




Information Conflict

- Conditions
  - Visual
    - Raised cosine
    - Constant velocity
  - Vestibular
    - Raised cosine
  - Visual-vestibular
    - Raised cosine velocity
    - Constant velocity (conflict)

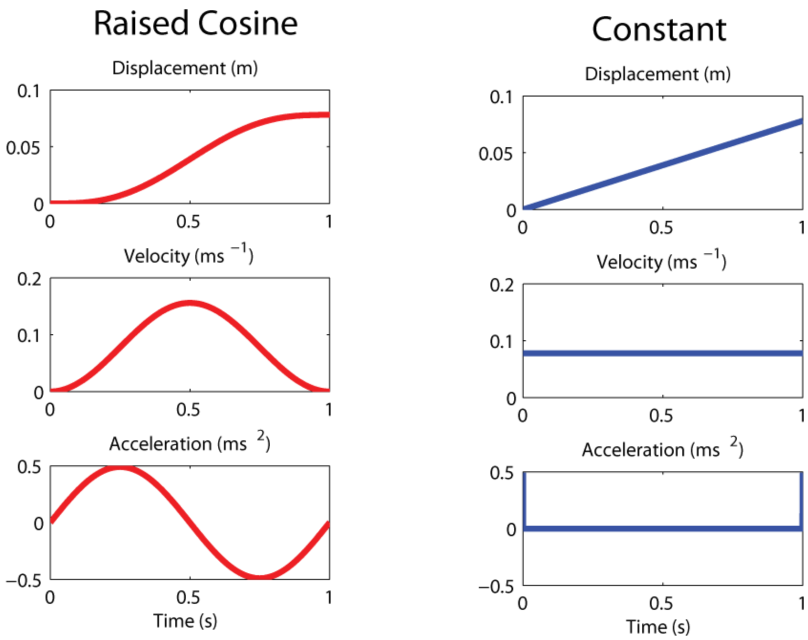




Visual motion Profile and heading estimation

Objective

To investigate if the velocity and acceleration play a role in visual heading discrimination



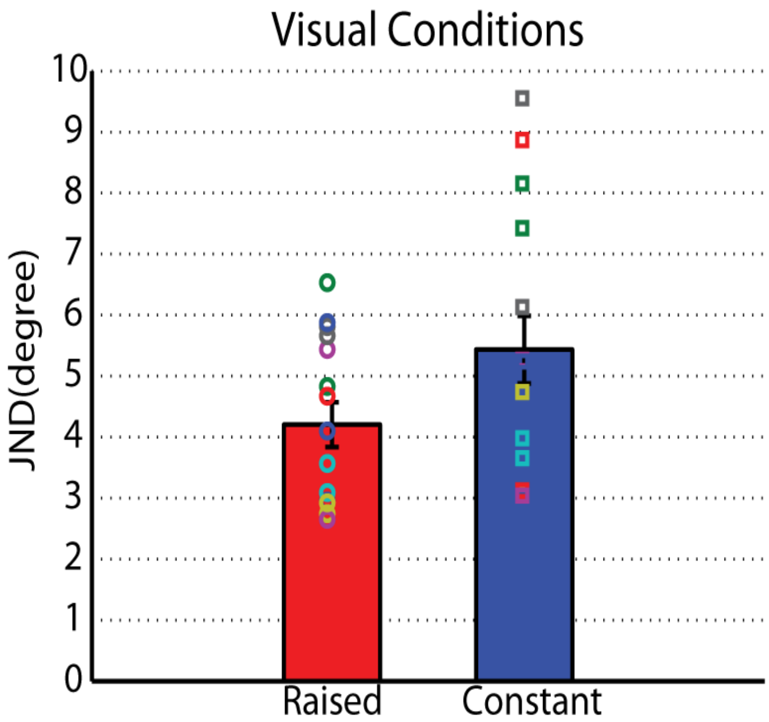
PREDICTION 1

The constant velocity profile will give more reliable results as it is highly predictable

PREDICTION 2

The more “natural” raised cosine profile is more reliably as we are more commonly exposed to it

Results



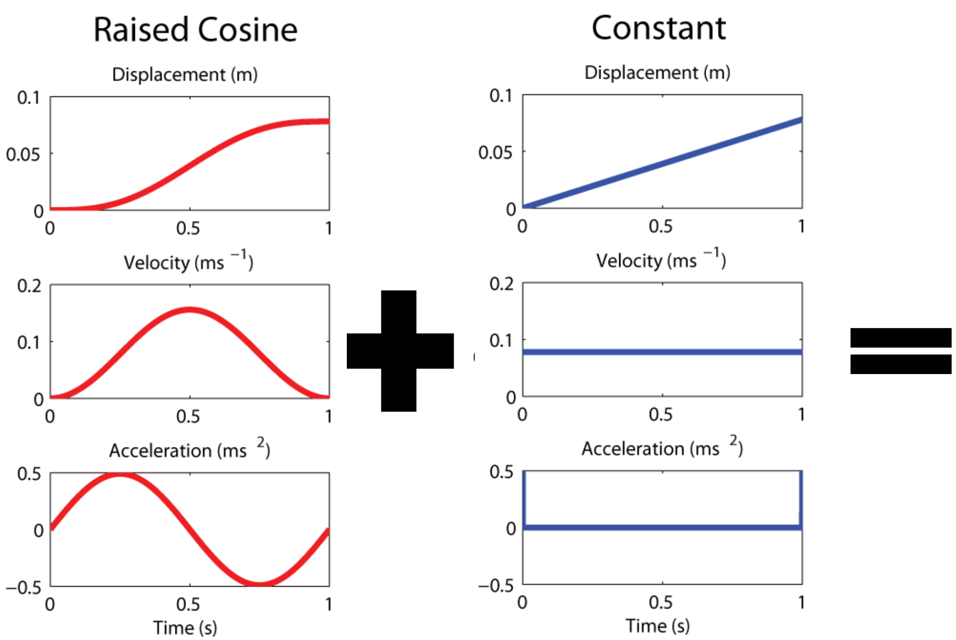
The raised cosine profile is gives more reliable estimates of visual heading

Predictions for the discrepant condition

Objective

To investigate the combination of visual and vestibular information under different visual motion profile conditions

Vestibular **Visual**



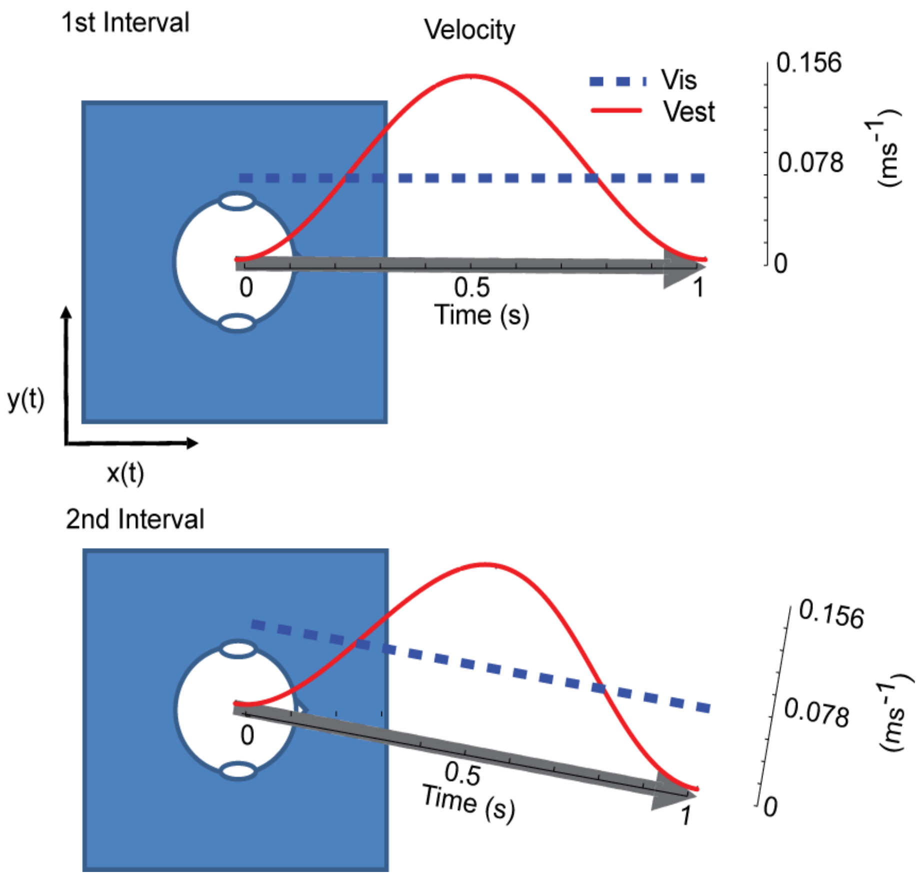
PREDICTION 1

The visual and vestibular information do not combine in an optimal fashion

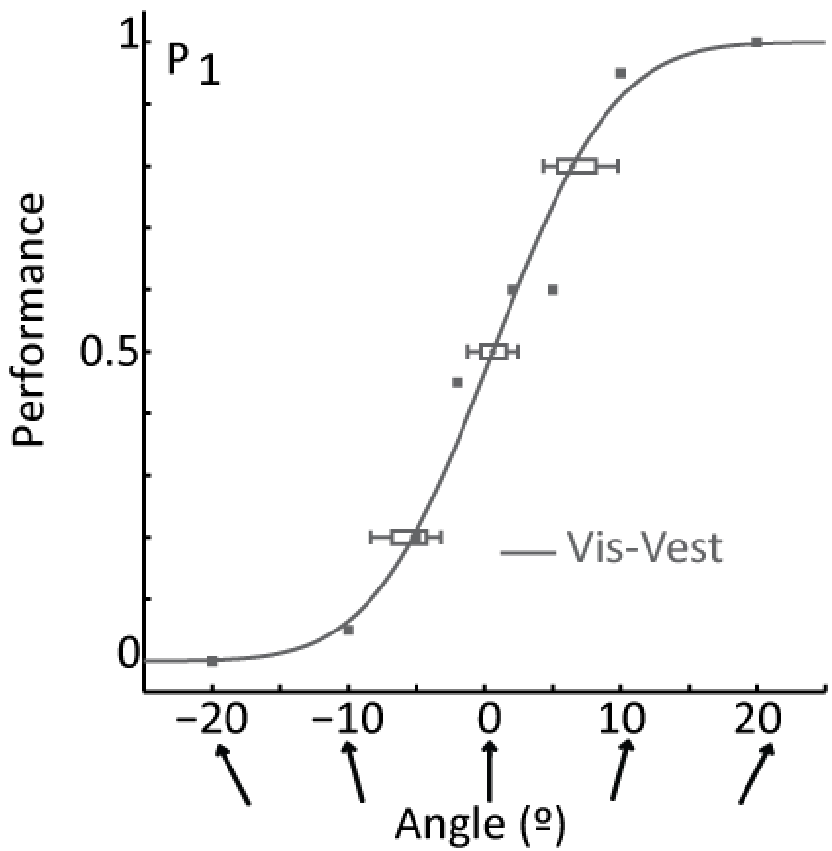
PREDICTION 2

Combination of senses is not dependent on the motion profile

Effect of visual motion profile on heading discrimination



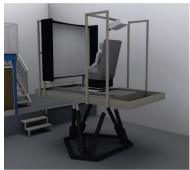
Combination of Senses



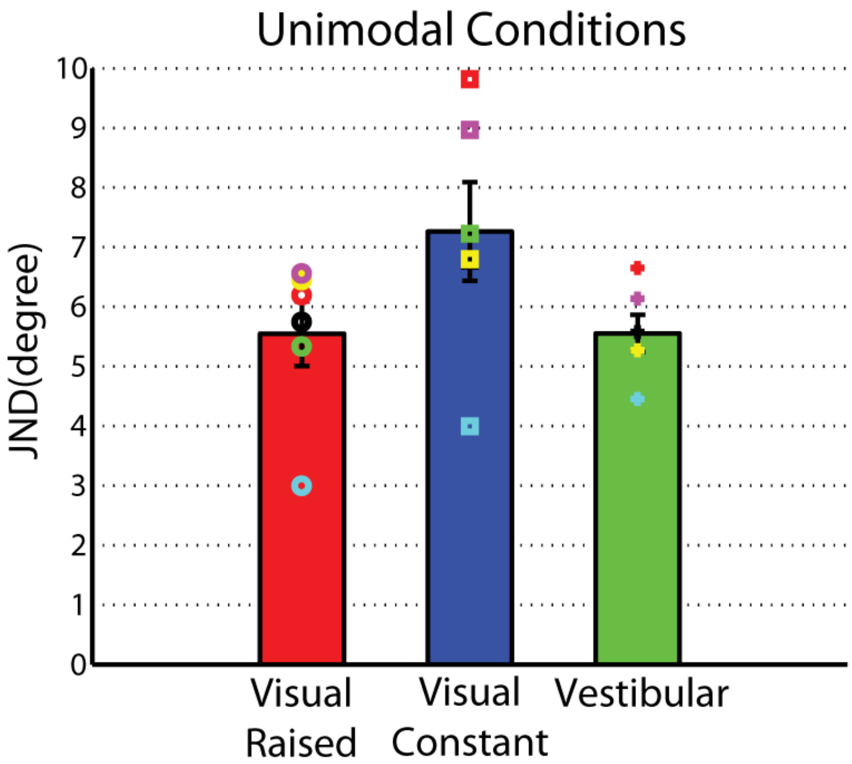
Predicted

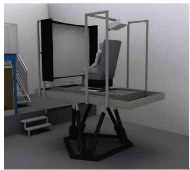
$$JND_{Vis-Vest} \leq \min(JND_{Vis}, JND_{Vest})$$

$$JND_{Vis-Vest} = \sqrt{\frac{JND_{Vis}^2 \, JND_{Vest}^2}{JND_{Vis}^2 + JND_{Vest}^2}}$$

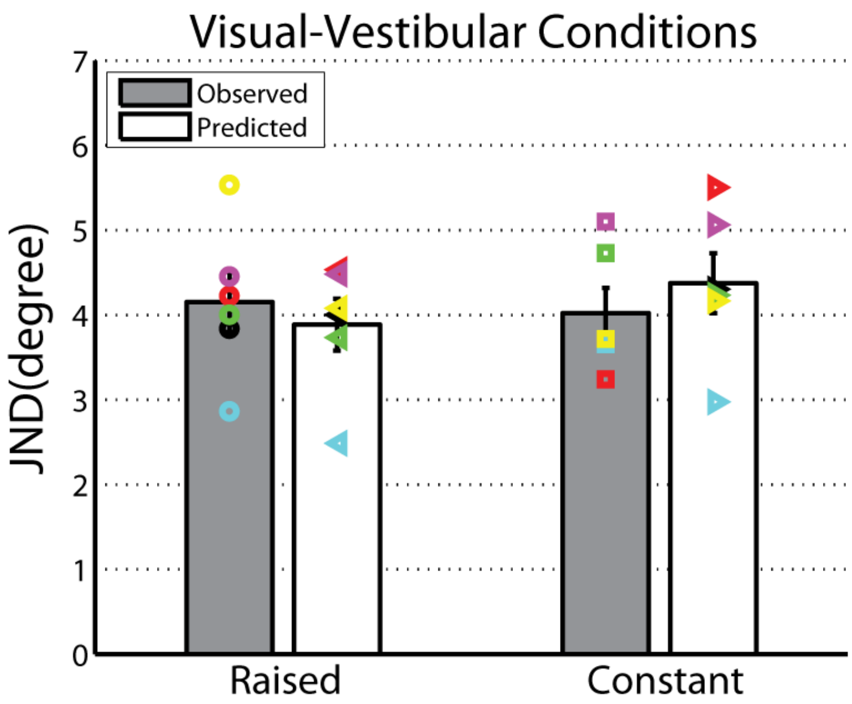


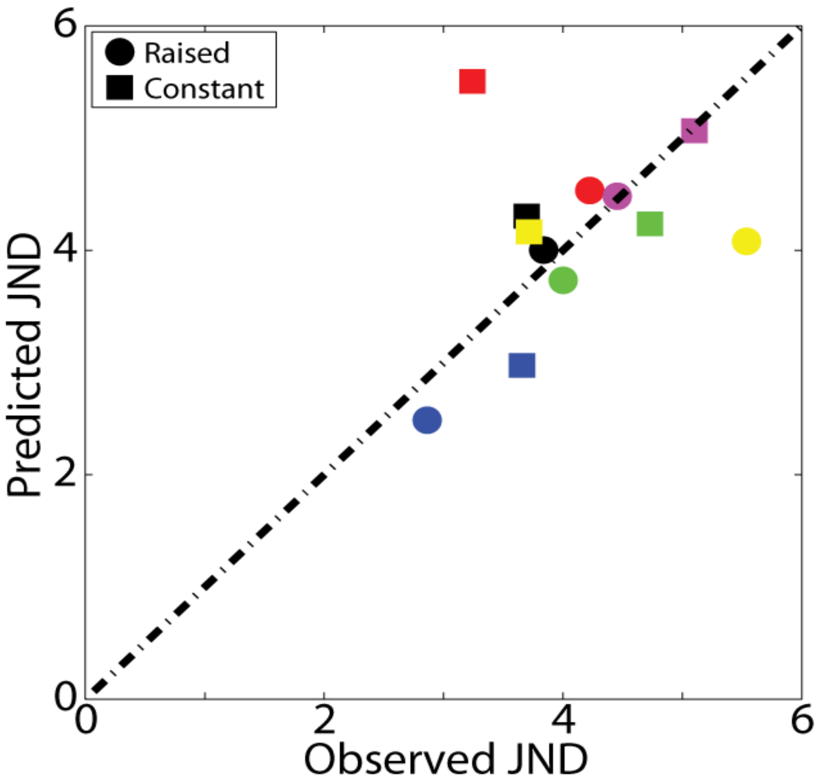
Unimodal results

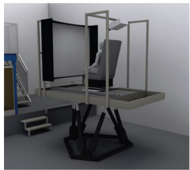




Multisensory Results







Conclusion

- Visual motion is not just a snap shot but an accumulation of information
  - The more natural profile yielded the more accurate heading discrimination

- Visual and Vestibular cues combine in an optimal fashion even when there is an information conflict

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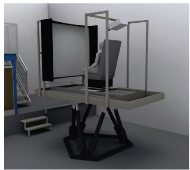
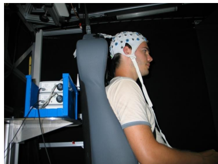


Neuronal Correlates of Self-Motion

- Behavioural tasks
  - Open loop
  - Closed loop

- Imaging techniques
  - fMRI
  - MEG
  - TMS
  - Imaging in non-human primates



Benefits of using EEG

- Systems level snapshot
- Attention deployment
- Temporal resolution
- Light weight
- Real world environment
- Online feedback loop
- ...

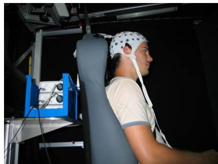
The cusp of a wave

HARDWARE

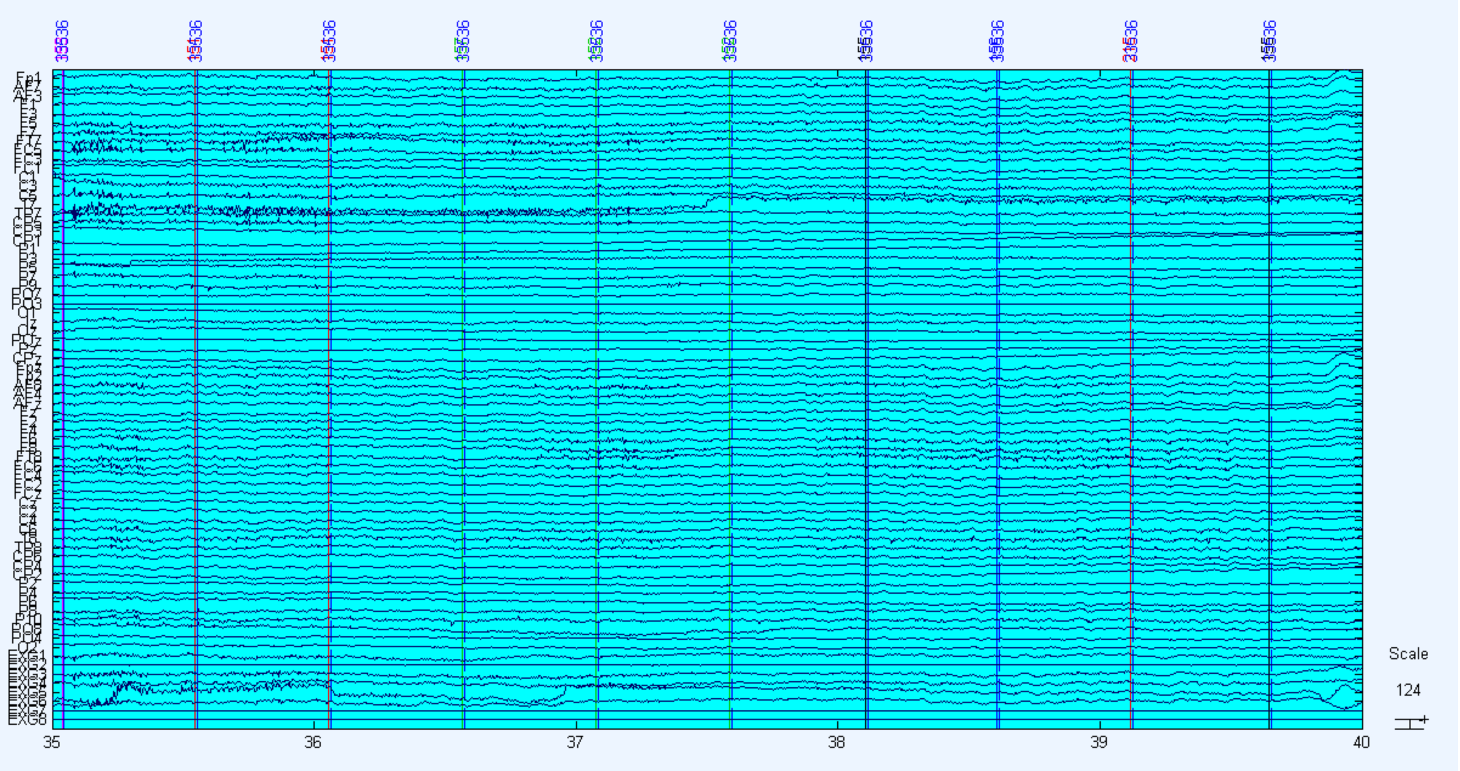
- Advances in motion platform design
- Advances in electrodes design

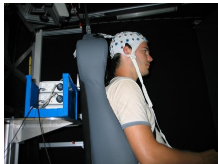
SOFTWARE

- Advanced analysis techniques
  - Independent Component Analysis
  - Source localisation techniques
  - Mobile Brain Imaging (MoBi – Scott Makeig)
- Individual data analysis
  - Bootstrapped Statistics

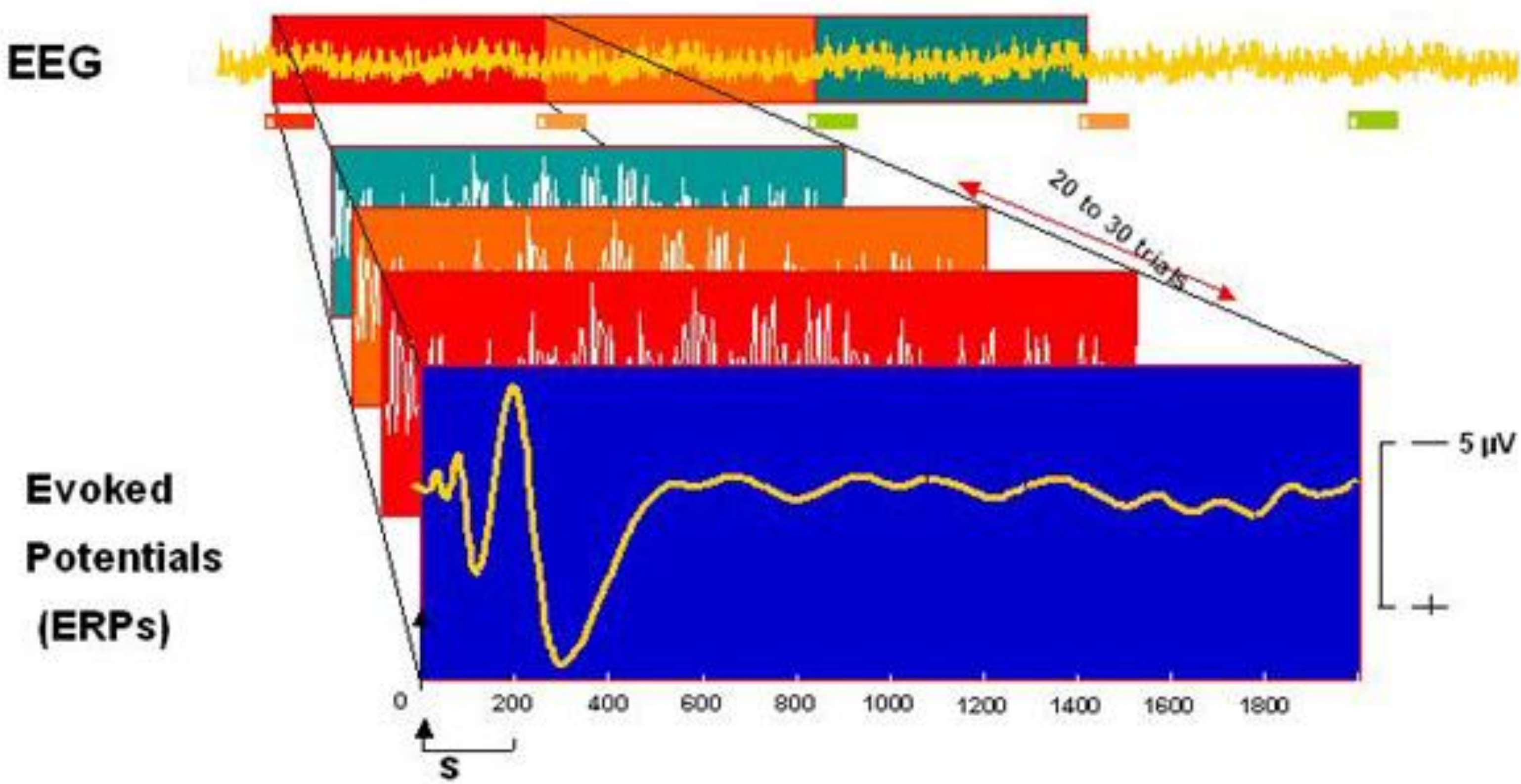


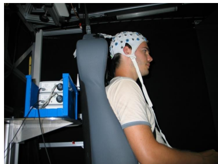
Electroencephalography (EEG)





Event-Related Potential (ERPs)





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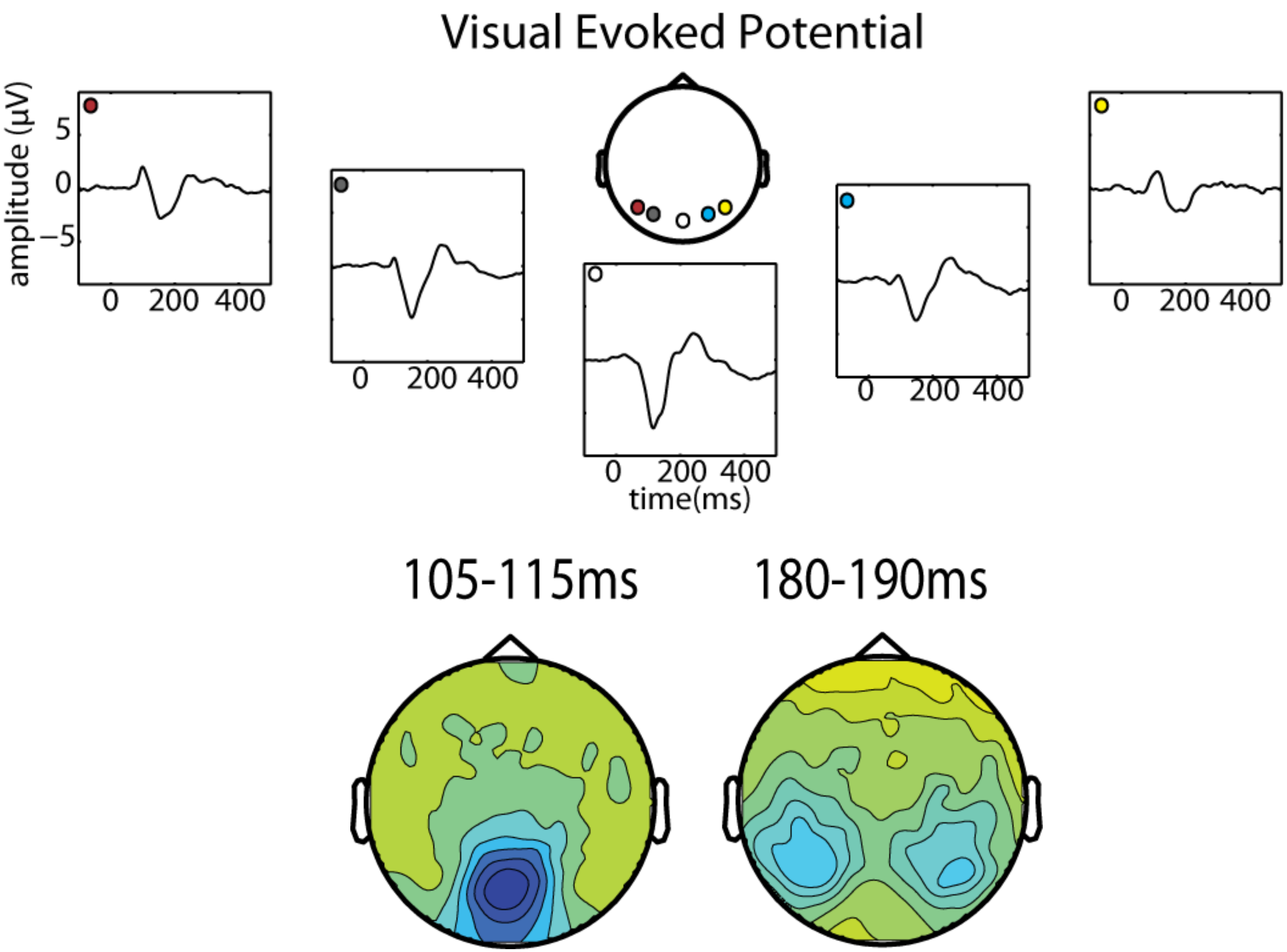
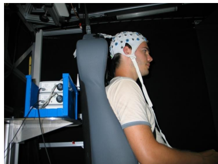




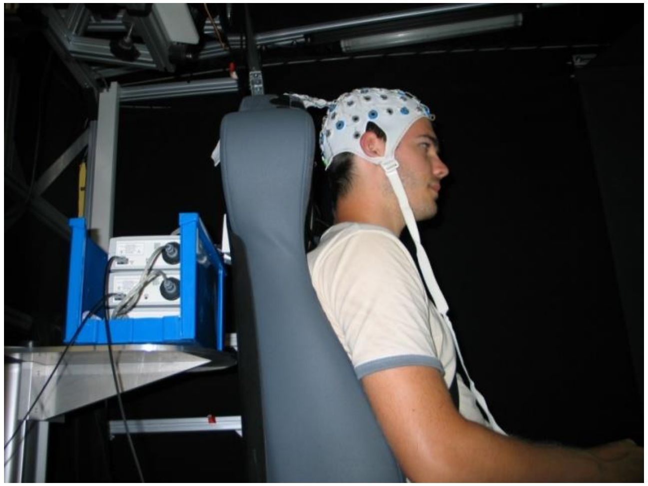
EEG on a Stewart Platform

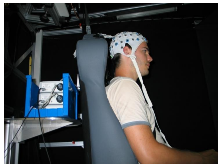
Experiment I

- EEG on the platform

Experiment II

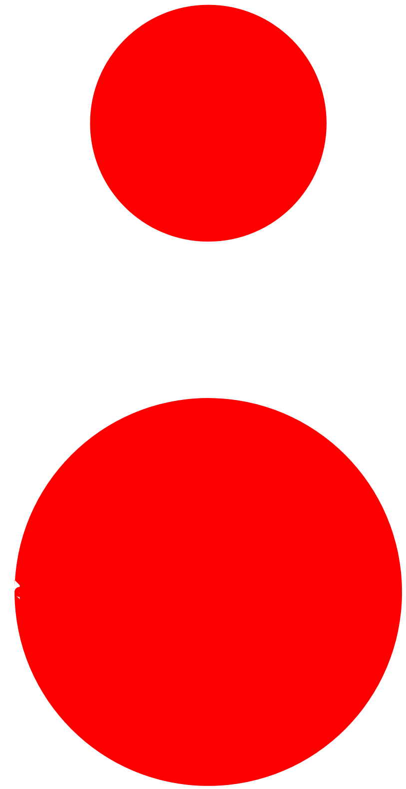
- Vestibular P3

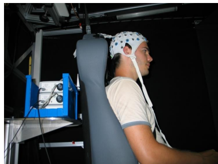




Control experiment

- Can we get an EEG signal while moving people?
- Visual P3 paradigm
  - 80% Standard
  - 20% Target
- Four levels of motion
  - Stationary
  - Idle
  - Slow 0.5 hrtz at 0.25mG
  - Fast 0.5 hrtz at 0.75mG



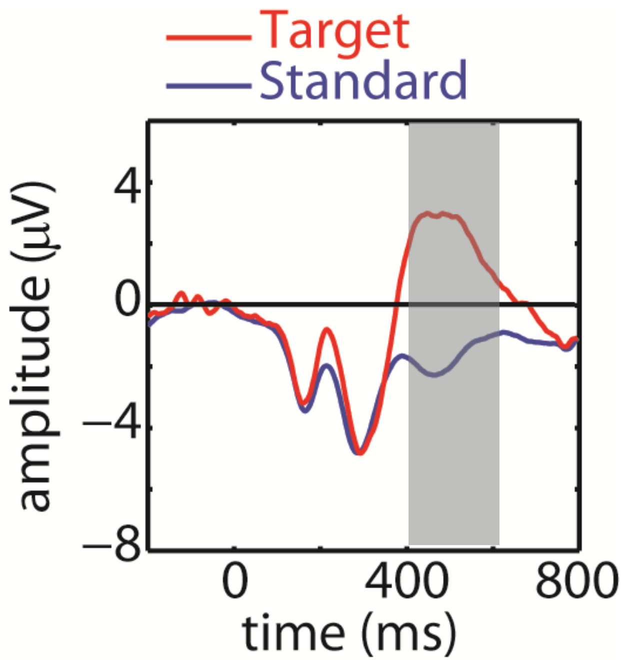


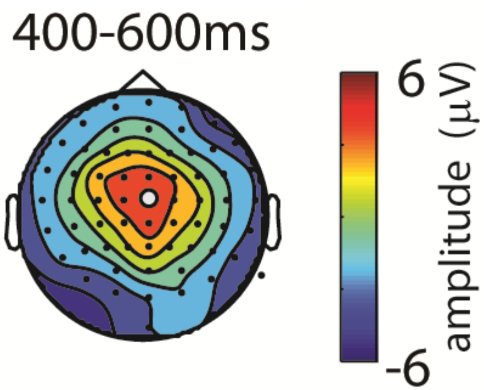
The Oddball Paradigm

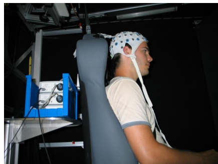
- Change detection is essential to interact with our environment

- Robust response elicited for visual, auditory, somatosensory and olfactory stimuli

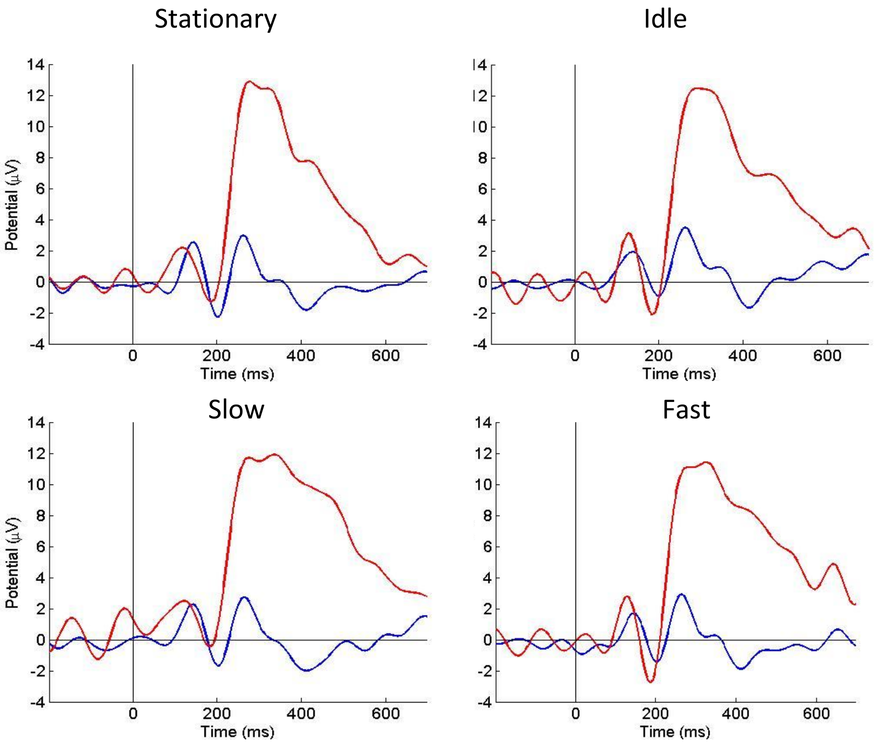
SSSTSSSSTSSSTSST







Results - Control Experiment



Summary

- We can conduct EEG on the motion platform

IEEE Neural Eng (2009)

Nolan, Whelan, Foxe, Bulthoff, Reilly, Butler

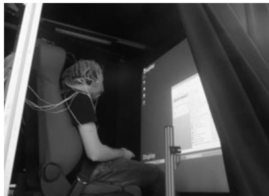
Vestibular Oddball

- Vestibular Conditions
  - Diagonal Left Target
  - Diagonal Right Target

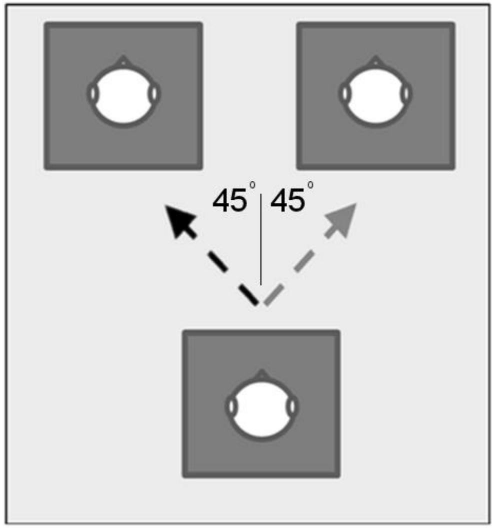
- Vestibular P3 paradigm
  - 80% Standard (320 sweeps)
  - 20% Target (80 sweeps)

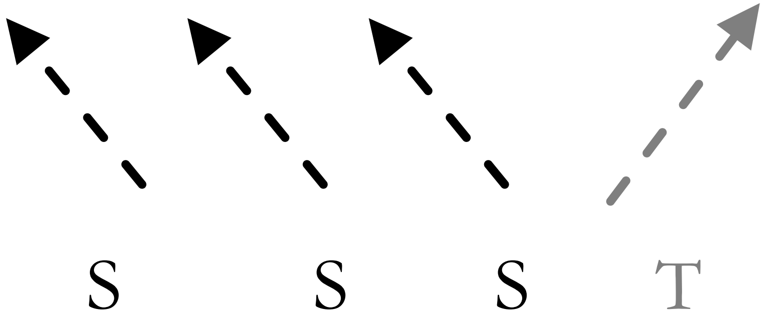
- 15 participants

- 128 scalp channels

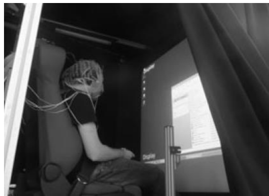


Procedure

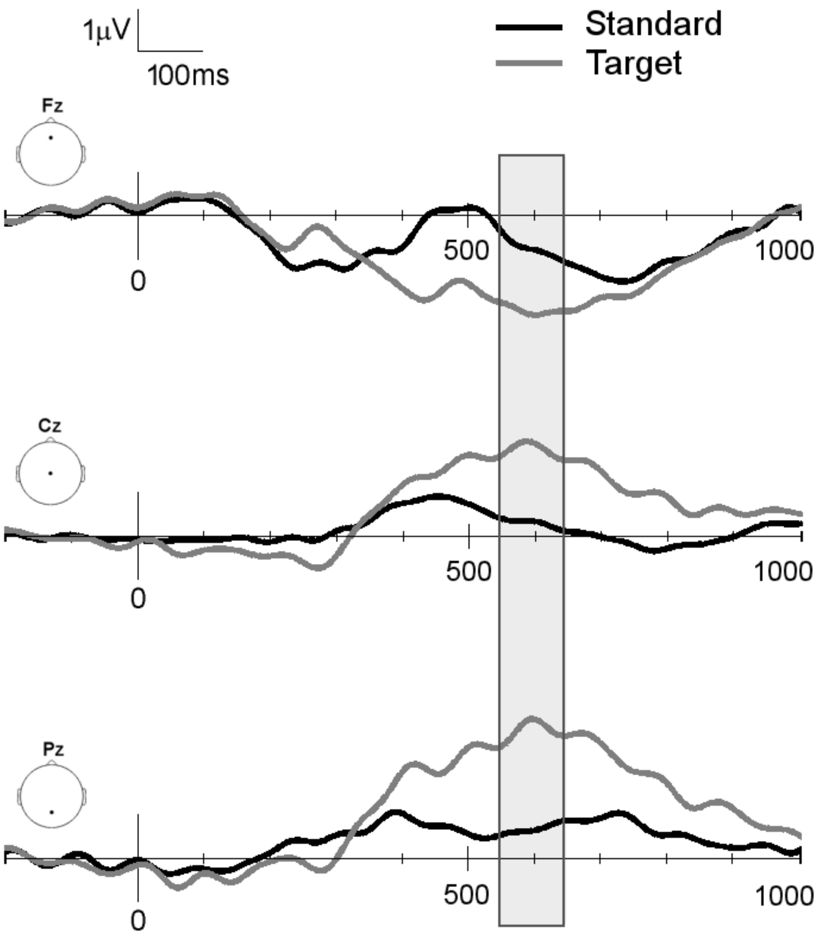




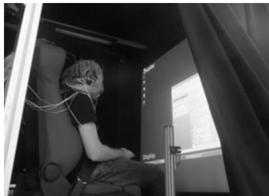
A neuronal marker for vestibular change detection



Results- Vestibular P3

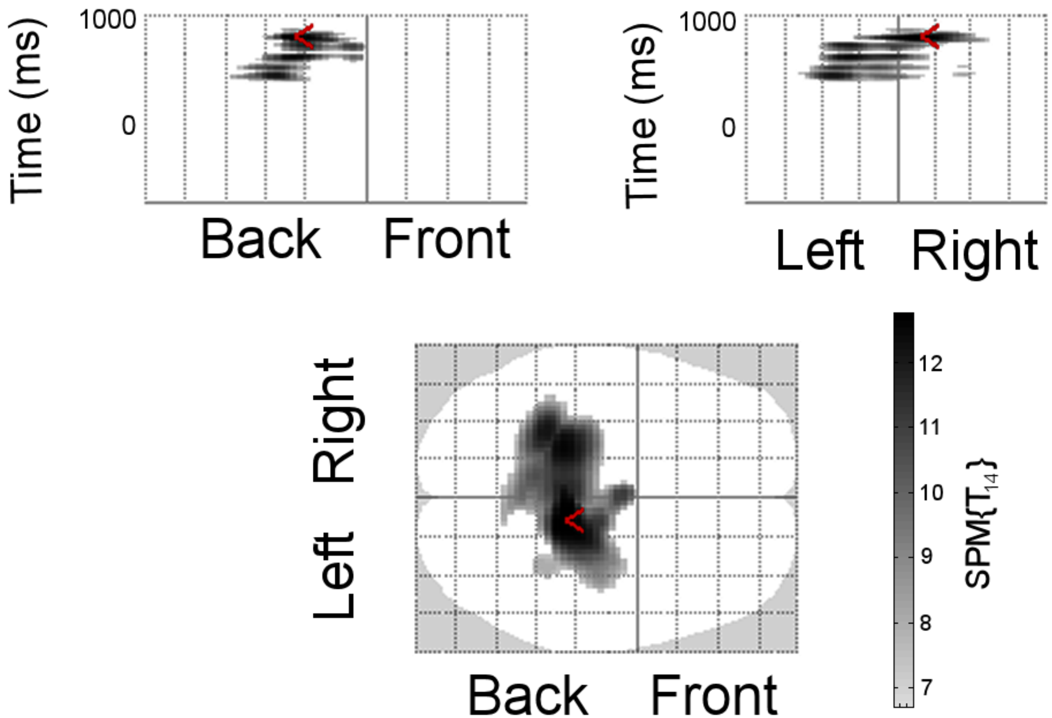


- Statistical difference between the standard and target

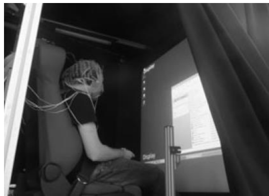


P3 distribution

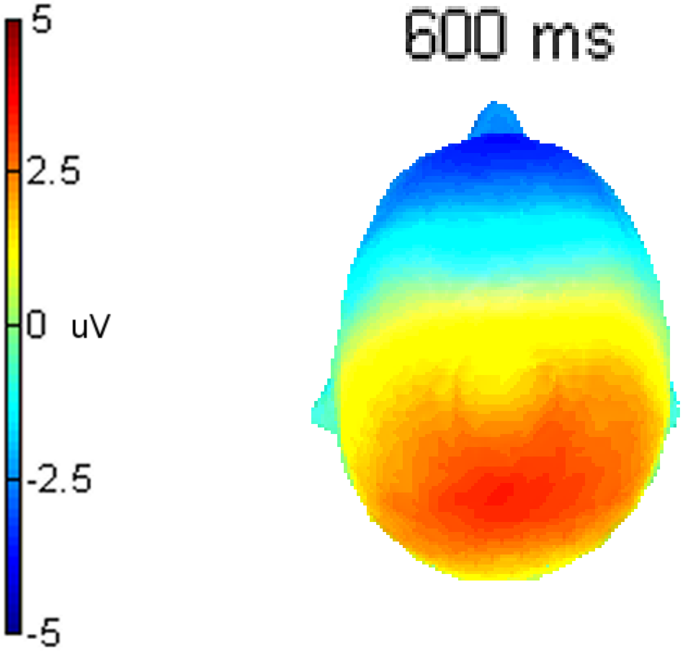
Target vs Standard



Target topographic scalp distribution is similar to the typical P3 distribution for other sensory modalities



Scalp Distribution



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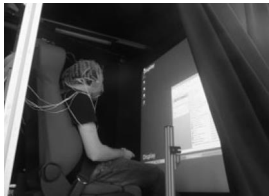
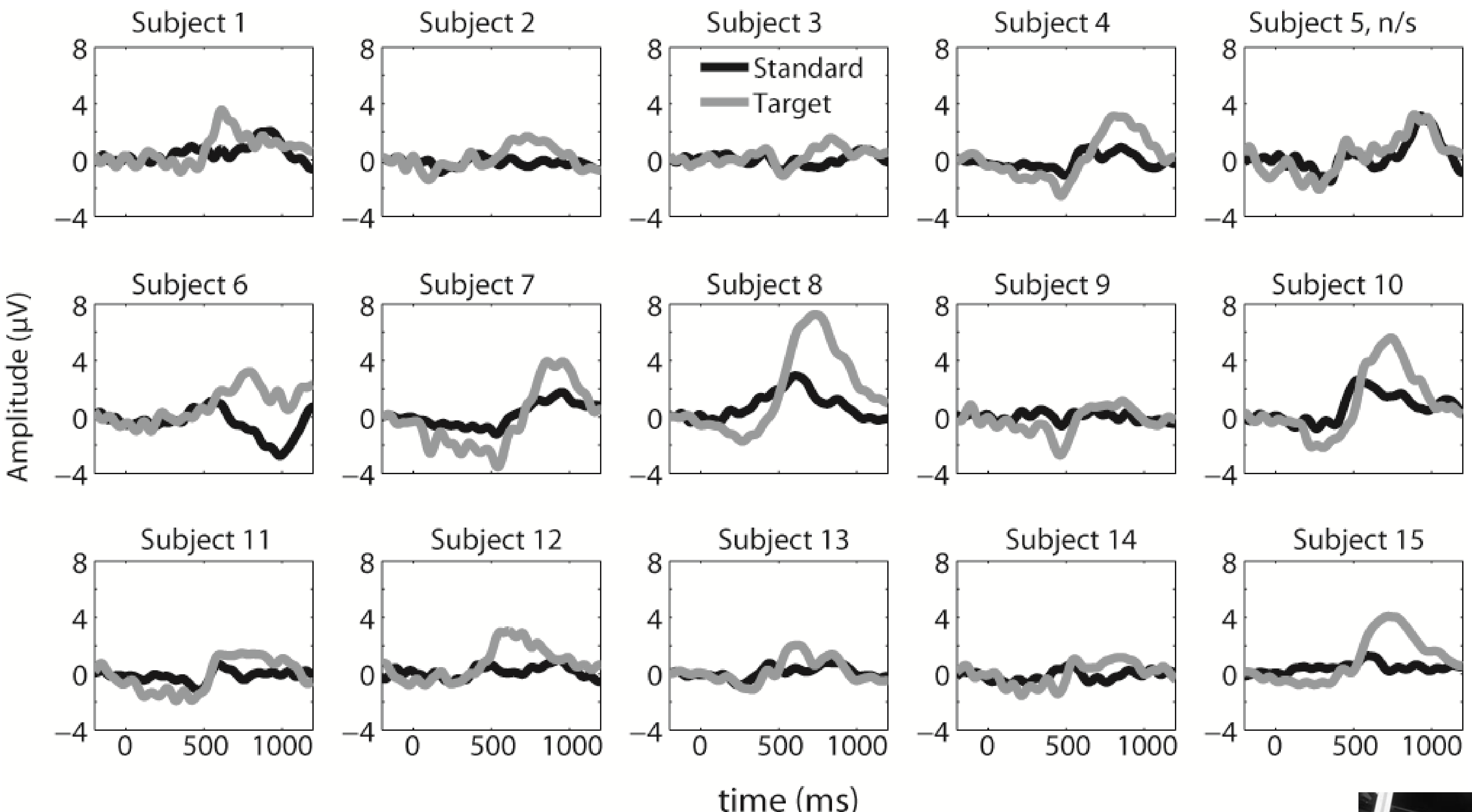
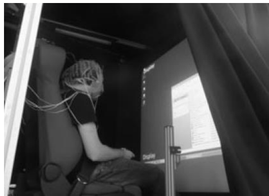


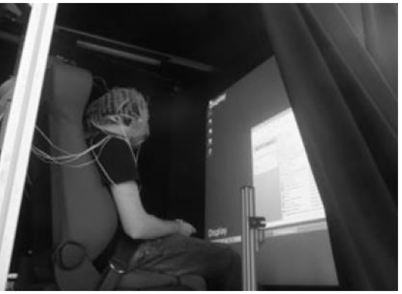
Individual Participant data



14 of 15 participants exhibited a P3



Summary



- This is the first time vestibular heading change detection has been shown to elicit a P3 component.

Nolan, **Butler**, Whelan, Foxe, Bulthoff, Reilly

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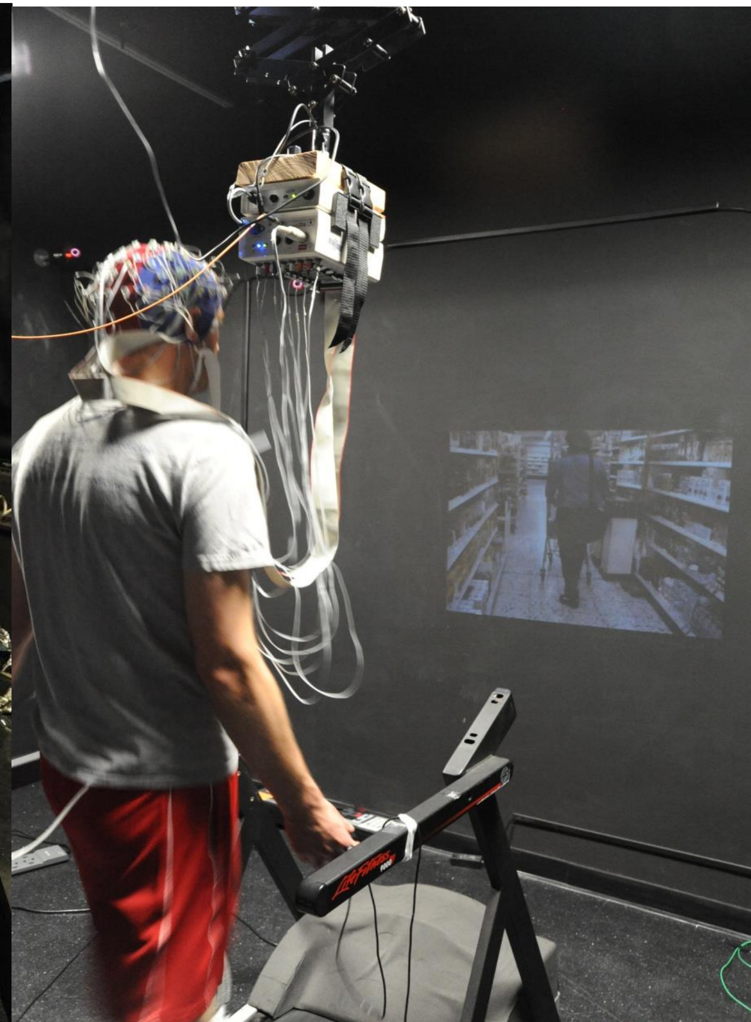
EEG while Walking



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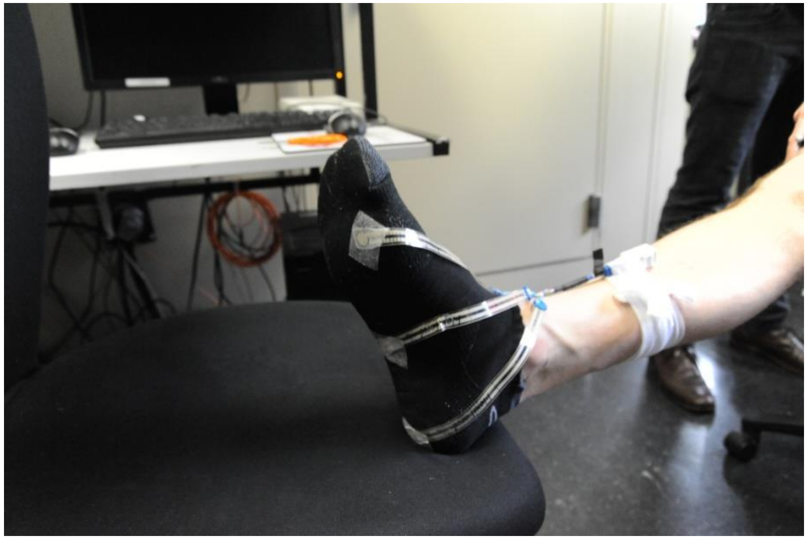

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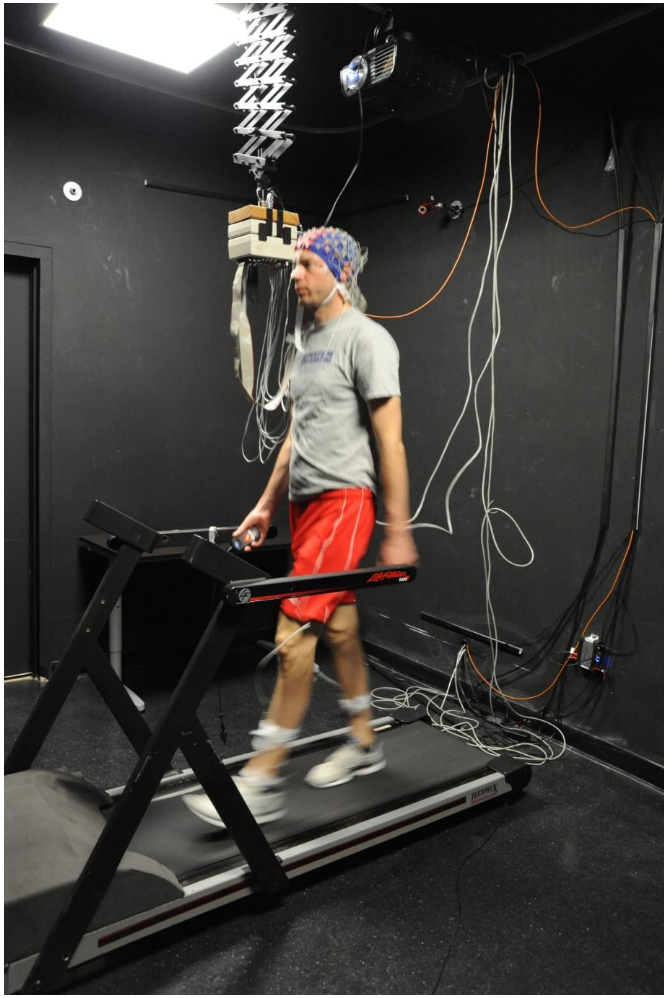
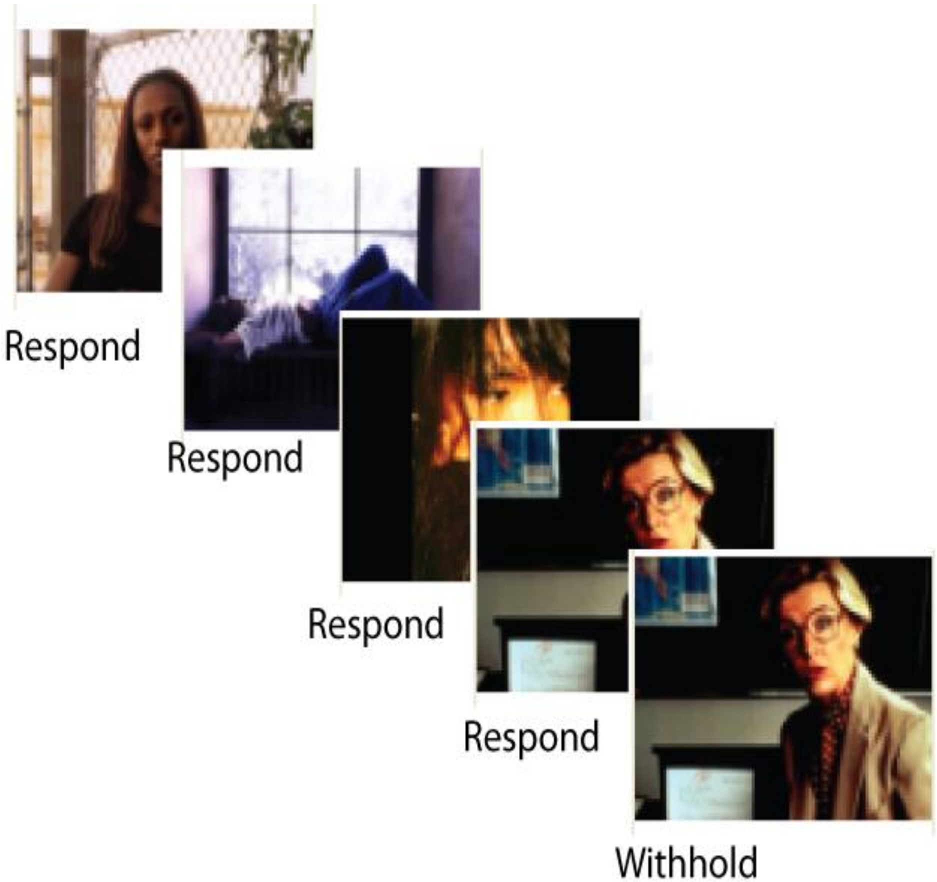
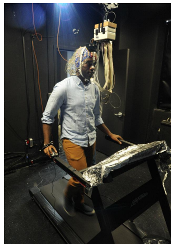


Response Inhibition Task



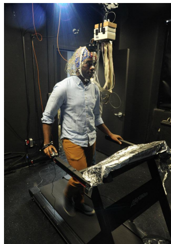
- Task
  - Go/Nogo Response Inhibition Task
  - NoGo: repetition of the same picture
  - Stimulus presentation rate 1/per sec
  - Go/Nogo = 80/20%
- Conditions
  - Sitting
  - Walking Slow (2.4 km/h)
  - Walking Fast (5 km/h)



Response Inhibition Task

- Hit:
  - correct response in a *go* trial
- Correct Rejection:
  - successful withholding of a response in a *nogo* trial
- False Alarm:
  - Executing a response in a *nogo* trial

1. Feasible to acquire usable EEG data while walking
2. Interaction of walking and response inhibition

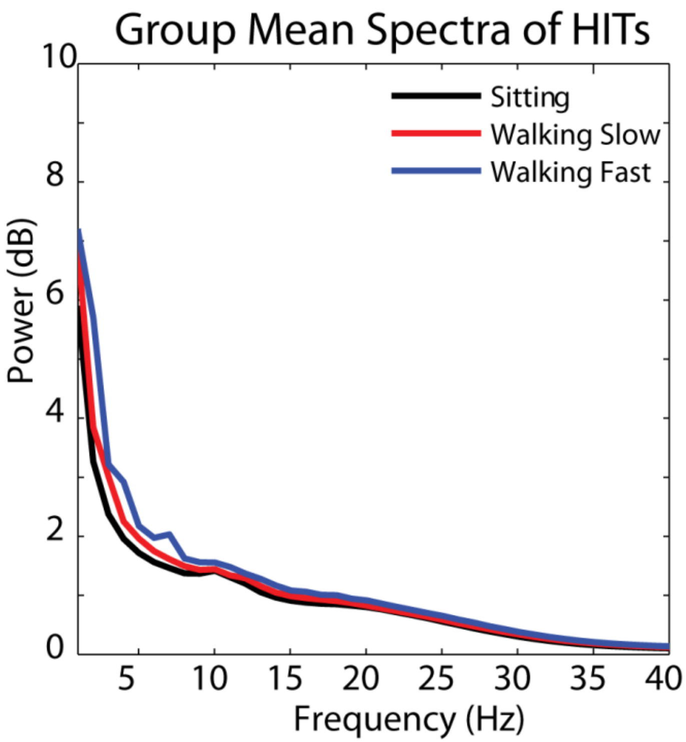


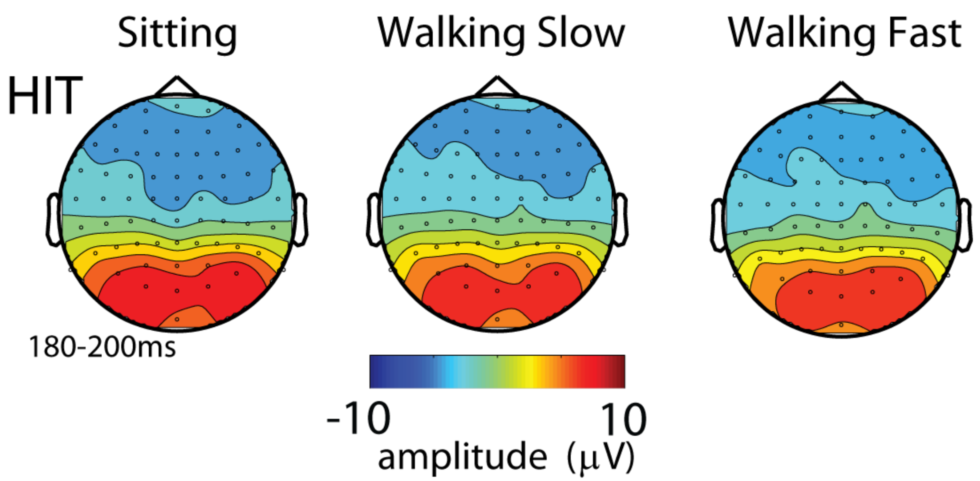
Behavioral and SNR Results

	Sitting	Walking Slow	Walking Fast	p-value
RT in msec	399.1	408.2	401.2	0.53
Hit in %	96.4	98.3	98.5	0.49
CR in %	68.6	70.4	69.4	0.6

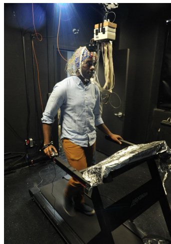
	Sitting	Walking Slow	Walking Fast
SNR Hit (dB)	54.8±2.3	53.6±1.6	49.9±2.2
SNR CR (dB)	35.3±2.0	34.0±2.5	32.6±2.2

Results

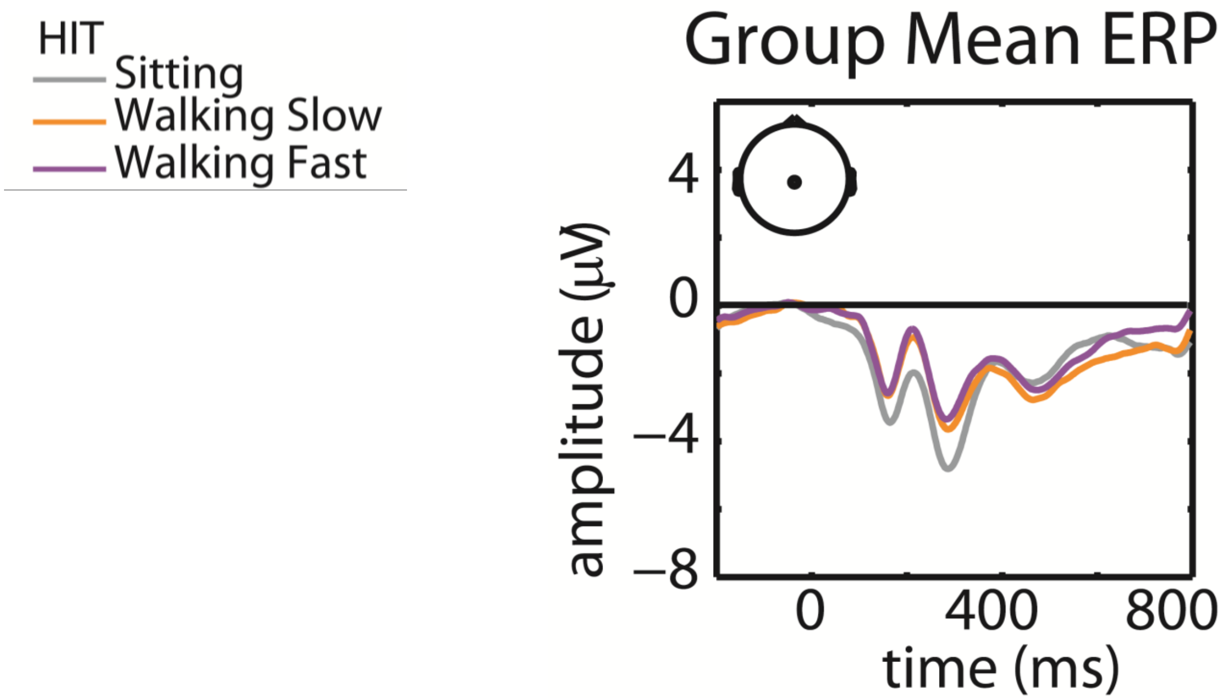


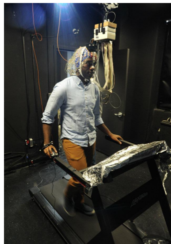


Highly similar early evoked response and power spectrum point to the feasibility of acquiring EEG while walking



Results



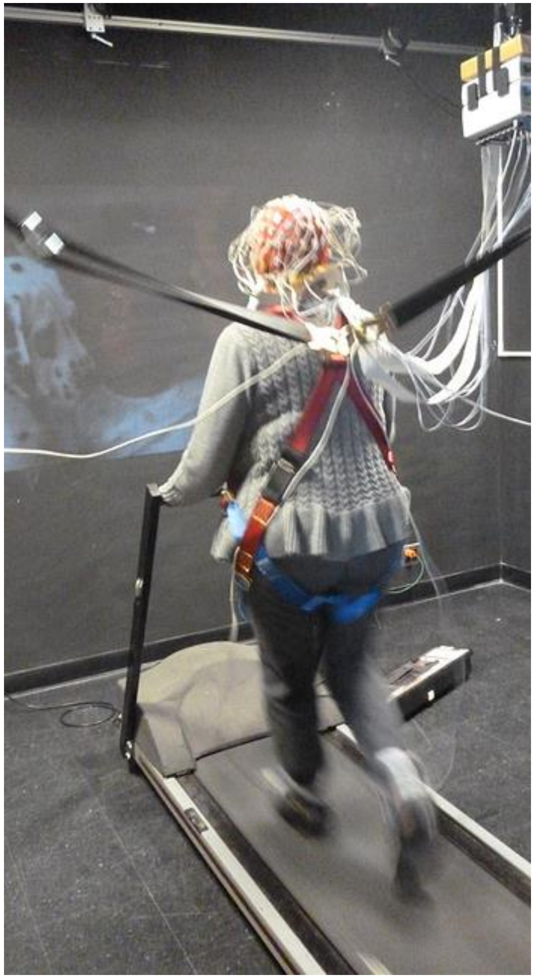


34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

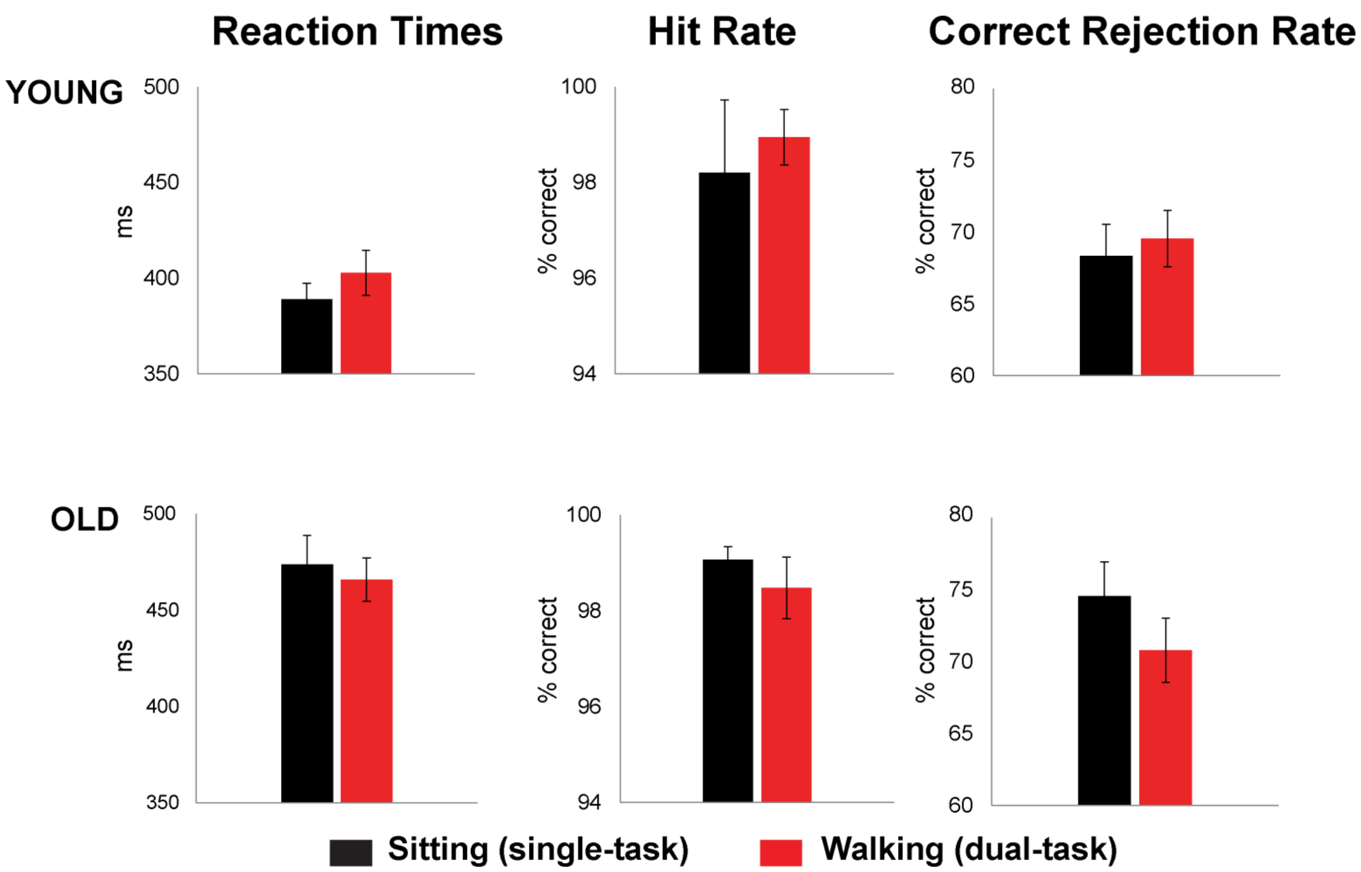
Pierfilippo De Sanctis, John S. Butler, Jason M. Green, Adam C. Snyder, and John J. Foxe

The aging brain shows less flexible reallocation of cognitive resources during dual-task walking: a mobile brain/body imaging (MoBI) study

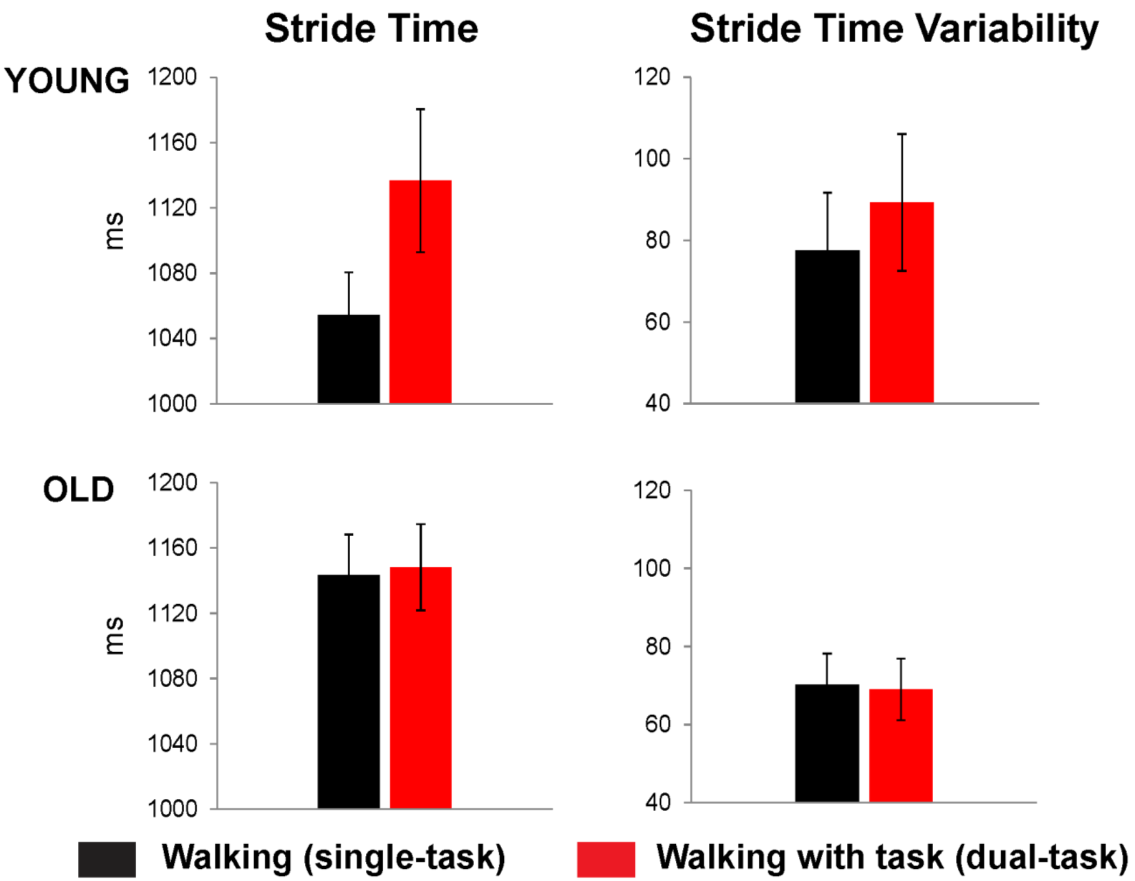
Age	Young	Old
Range	21.8-36.1	57.7-71.0
Mean	27.2	63.9
SD	4.6	4.0
	N=18	N=18



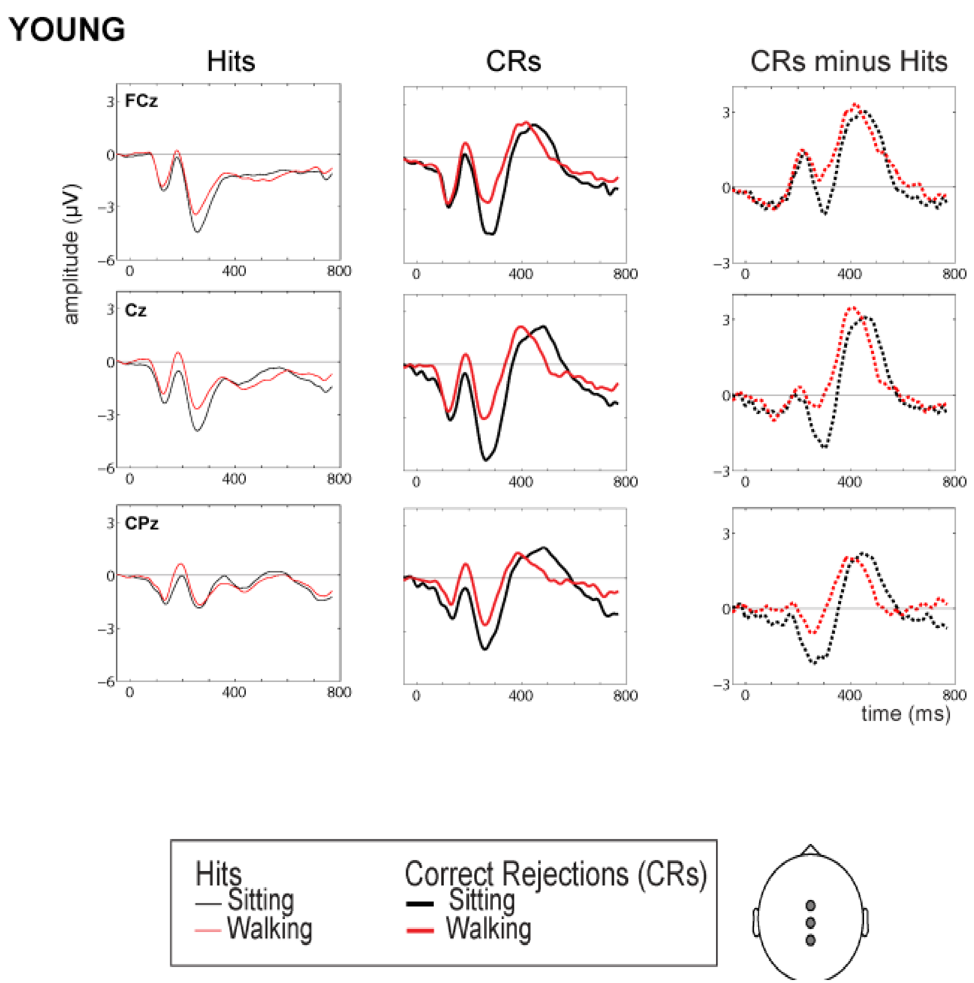
Behavioural



Gait Parameters

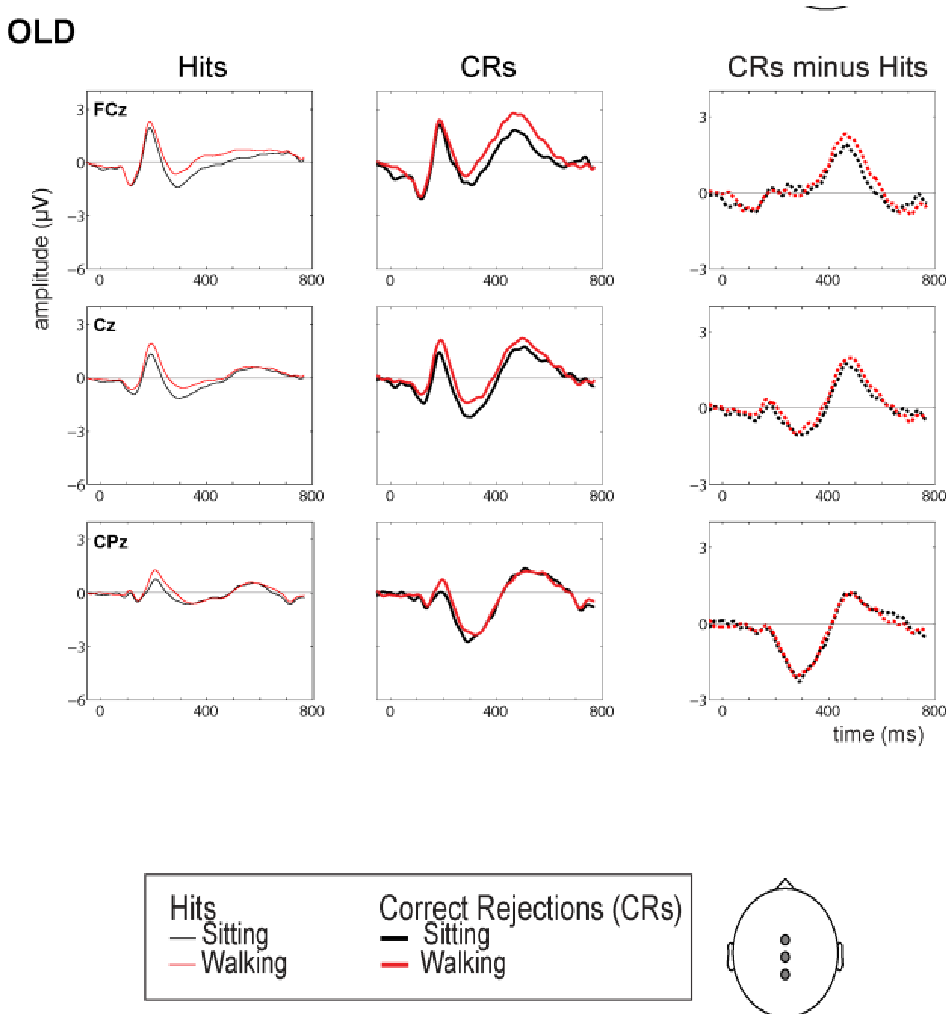


ERP - Young

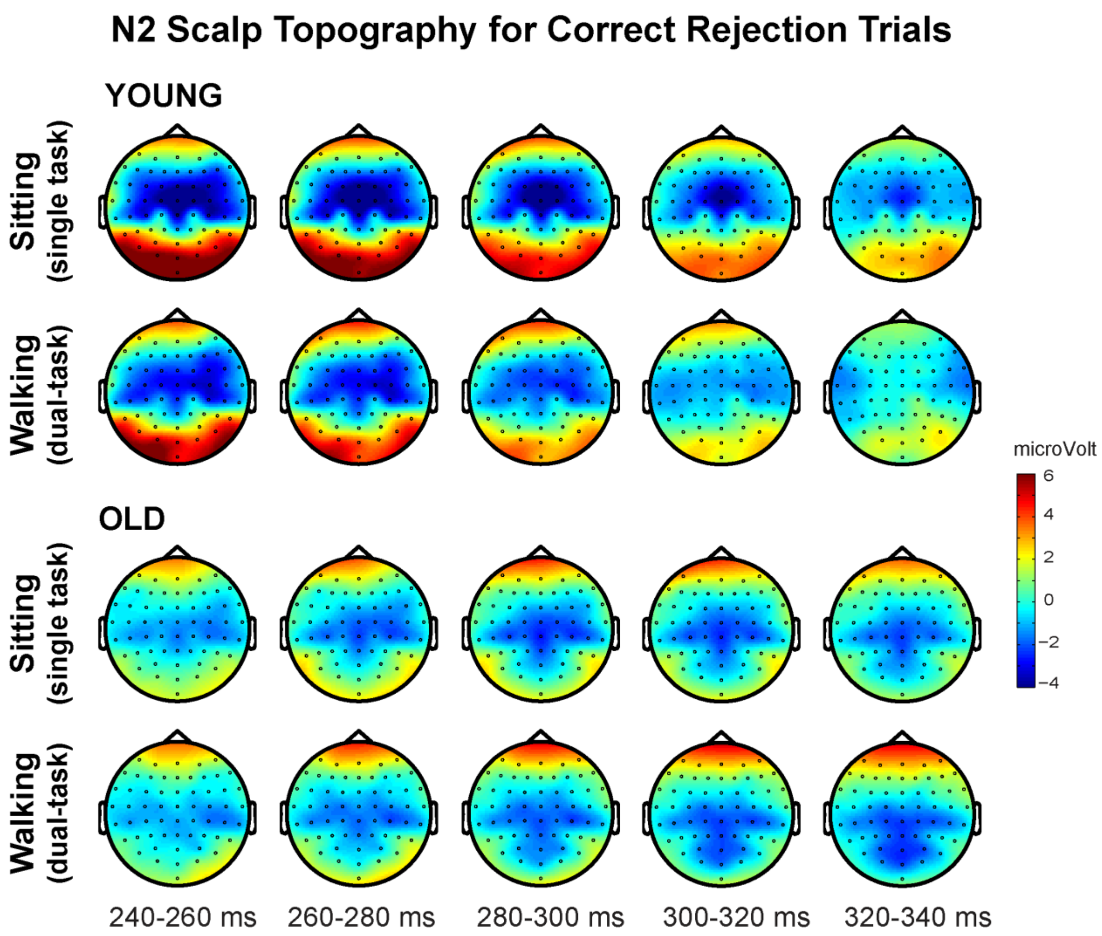


YOUNG
Hits
CRs
CRs minus Hits
FCz
Cz
CPz
amplitude (µV)
time (ms)
3
0
−3
−6
0
400
800
Hits
Sitting
Walking
Correct Rejections (CRs)
Sitting
Walking

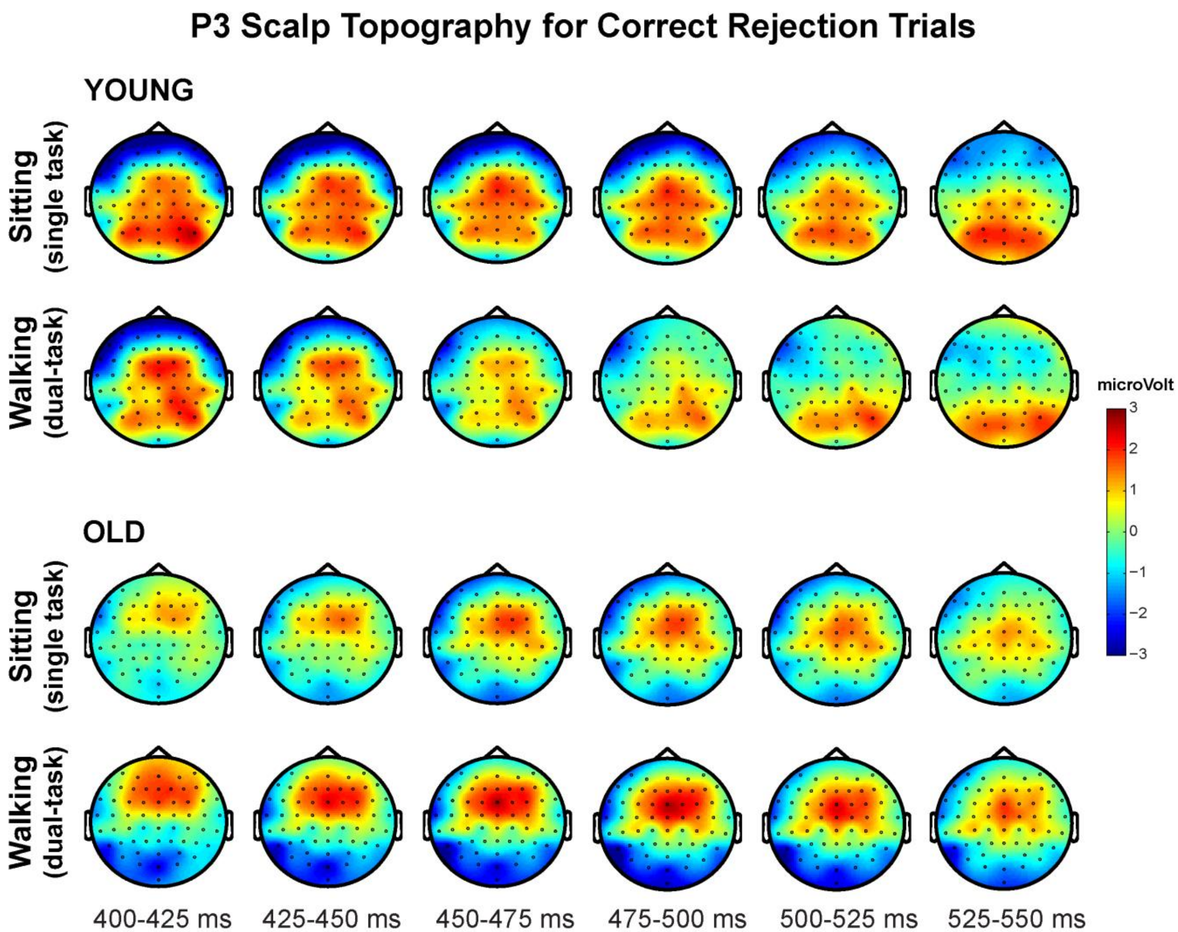
ERP - Old


OLD
Hits
CRs
CRs minus Hits
FCz
Cz
CPz
amplitude (µV)
time (ms)
Hits
Sitting
Walking
Correct Rejections (CRs)
Sitting
Walking

N2 topographical distribution



P3 topographical distribution



Summary

- Younger adults adjust gait and cognitive control when presented with a dual task situation
- Healthy older adults show a lack of flexibility, both in terms of adjusting physical behavior and in reconfiguring cognitive control mechanisms at the neural level.

Conclusion

- These studies provide highly promising methods for gaining insight into the neurophysiological correlates of self-motion in more naturalistic environmental settings.

- Further our understanding self-motion disorders

Overall Conclusion

- The vestibular system is useful
  - Combines in an optimal fashion with visual cues
  - Is processed like other sensory modalities
- EEG can be collected during active and passive motion
  - With meaning results that further our understanding of self-motion

Thank you

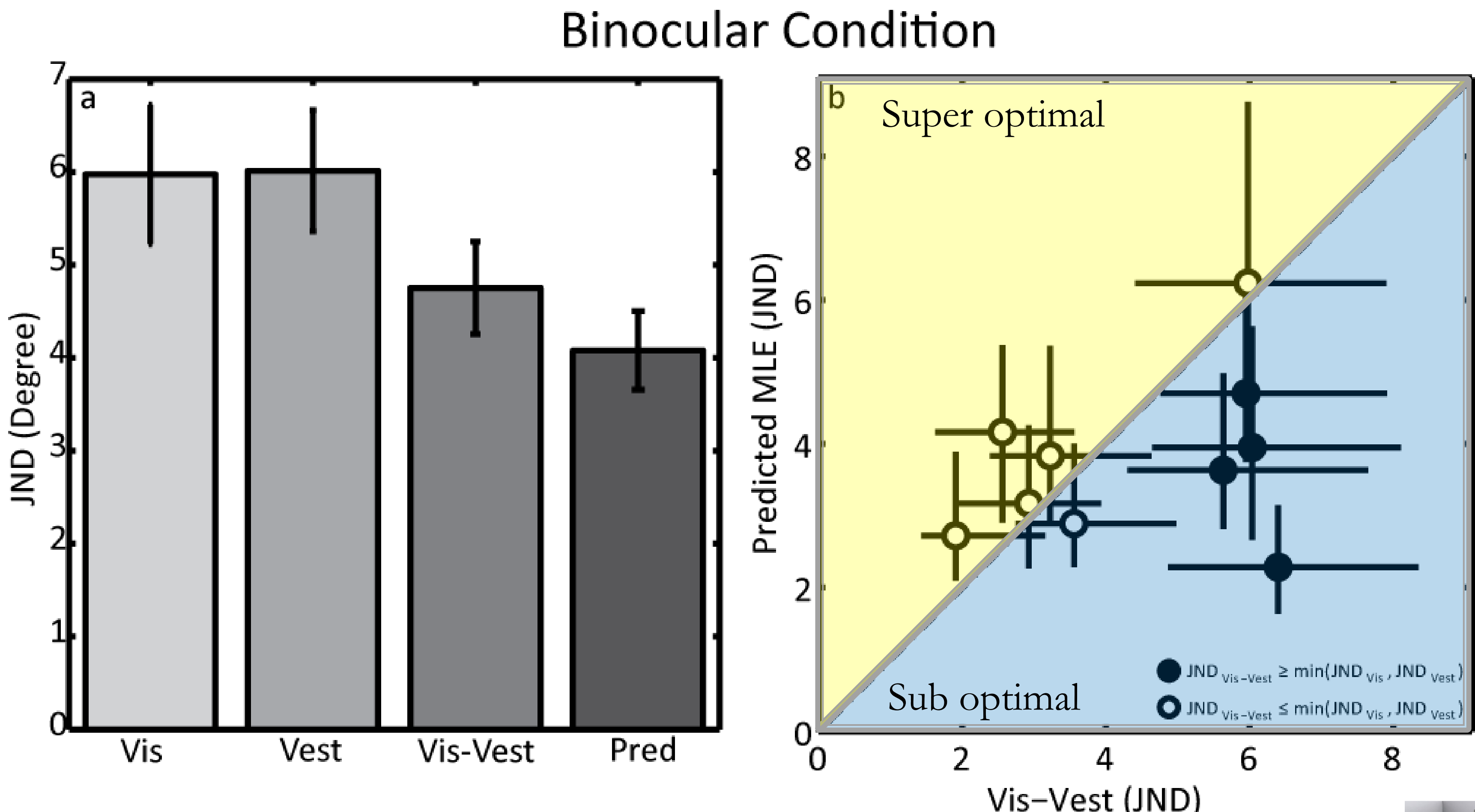
Albert Einstein College of Medicine
Adam Snyder
Brenda Malcolm
Pierefilipo DeSanctis
John Foxe

Trinity College Dublin
Hugh Nolan
Robert Whelan
Richard Reilly

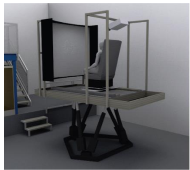
Max Planck Institute for Biological Cybernetics
Jennifer Campos
Heinrich Bülthoff

Any questions

Binocular Condition

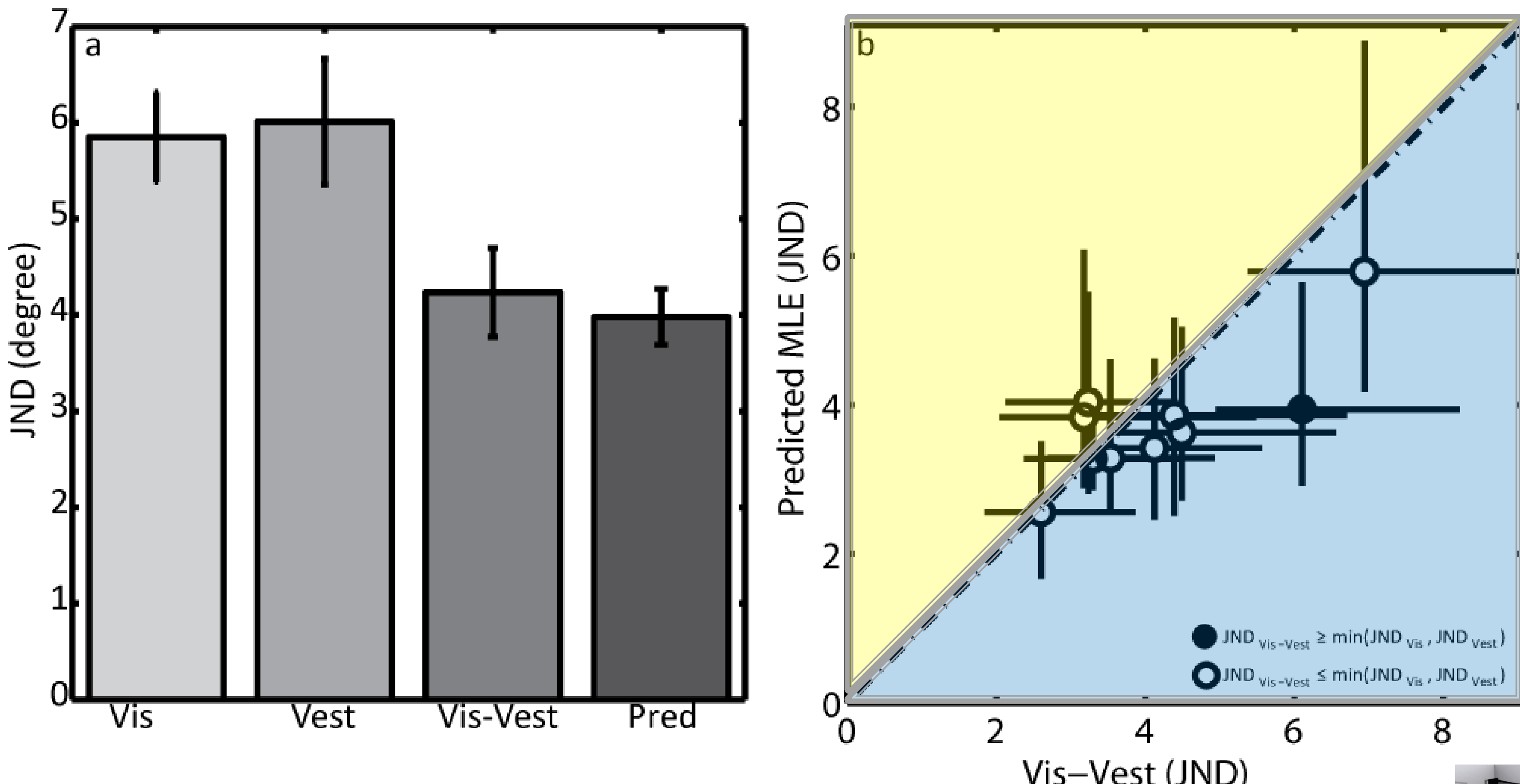


6 of the 10 exhibit optimal combination of sense



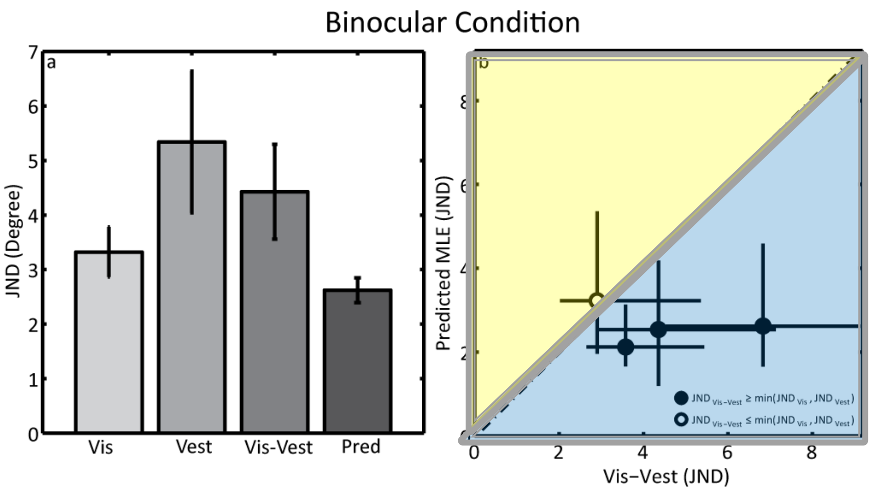
Stereoscopic Condition

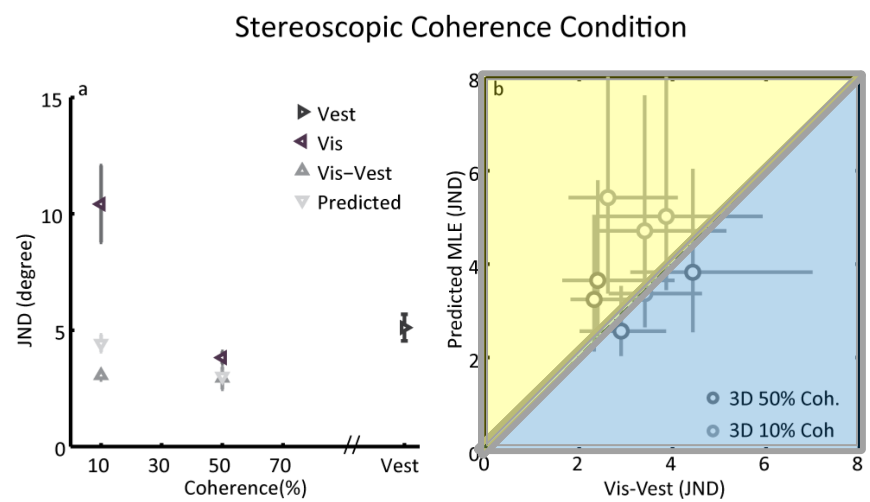
Stereoscopic Condition



9 of the 10 exhibit optimal combination of sense

Reproducible nature of result



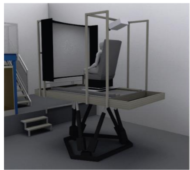


A subset of the original participants were re-run and exhibited identical results

Summary

- The presence/absence of stereoscopic visual information can impact the extent to which visual and vestibular cues are integrated during heading perception.
- This was reproducible within participants

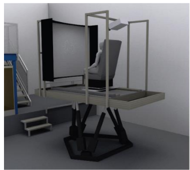
J. S. Butler et al. / *Seeing and Perceiving 24 (2011) 453–470*



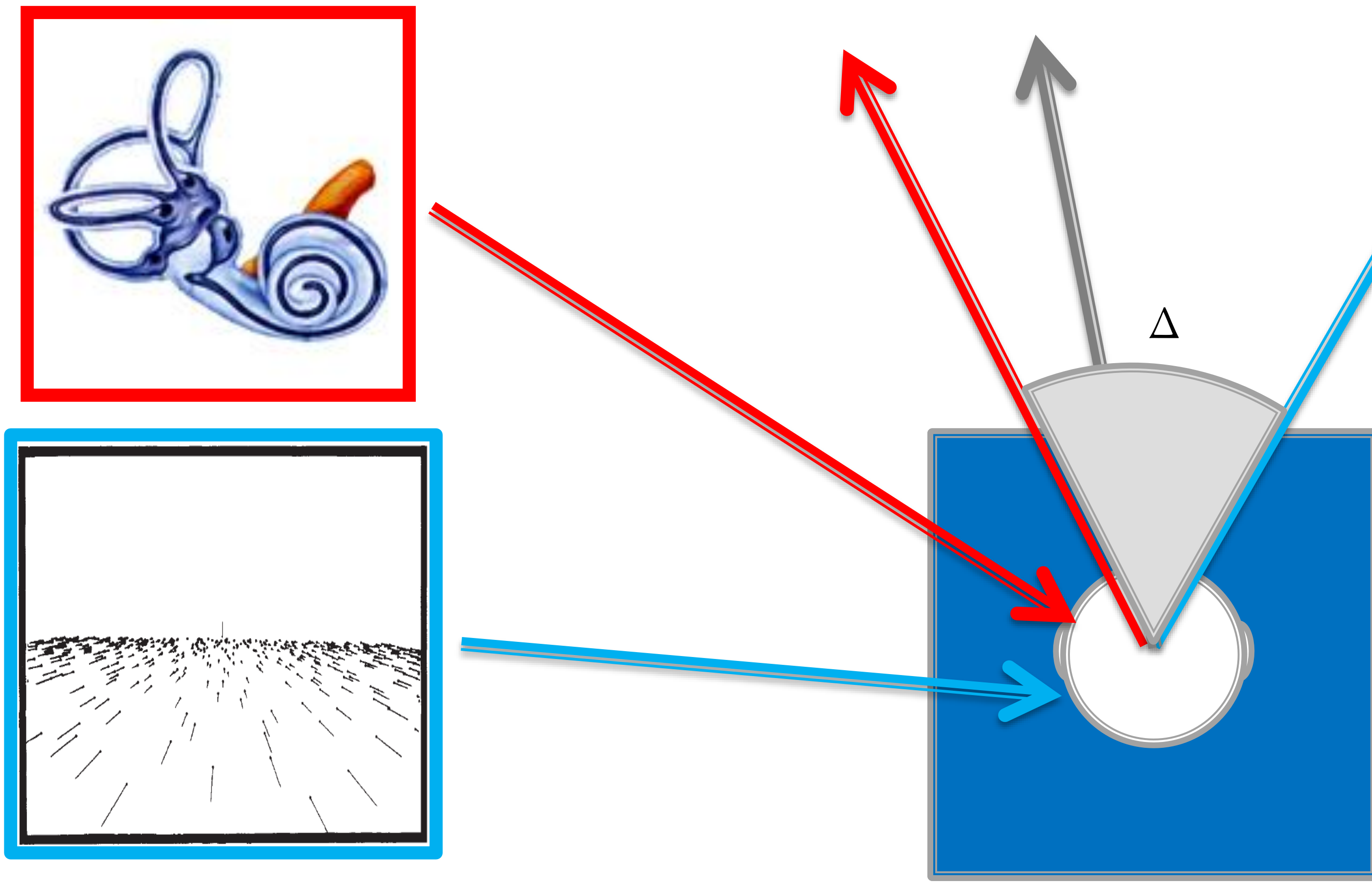
Talk Overview

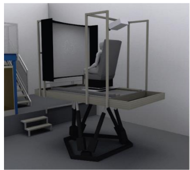
- Passive Heading detection
  1. The role of Stereo cues
  2. Conflict of information
  3. Neural correlates of heading detection change

- Active tasks
  4. Walking
  5. Neural recordings while walking



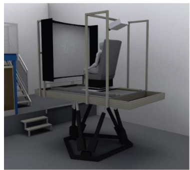
Visual-Vestibular Integration for Heading (conflict)





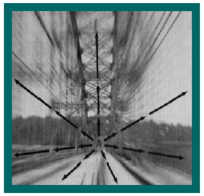
Why introduce a conflict?

- By introducing a conflict we can see if there is a breakdown of the combination of sense
- We can calculate the weights given to each cue

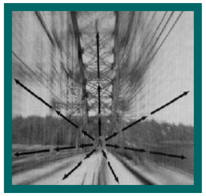


The logic of conflicts

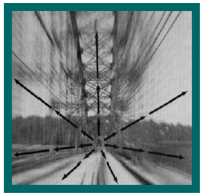
Equally weighted

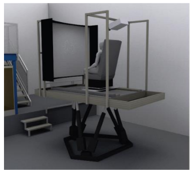


Vestibular weighted more

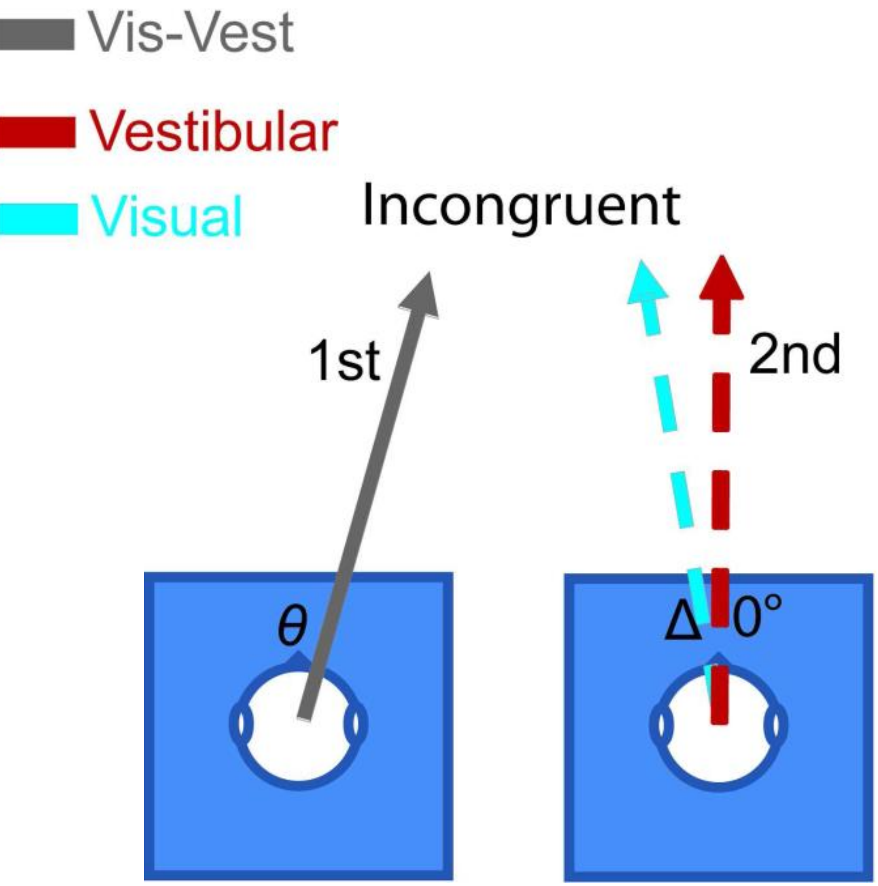


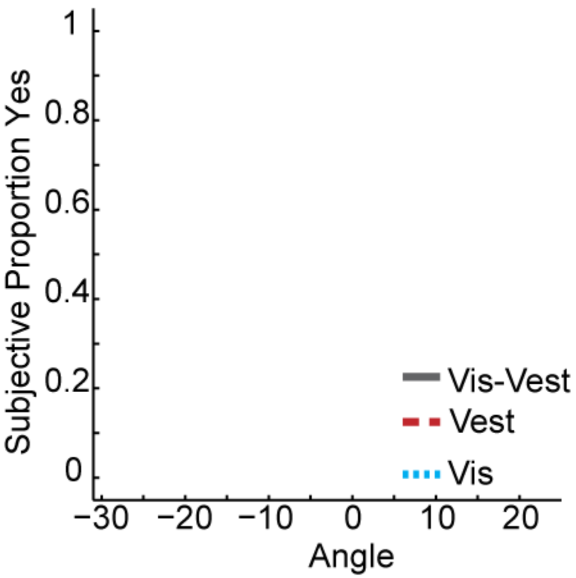
Vision weighted more

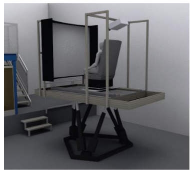




Individual participant analysis







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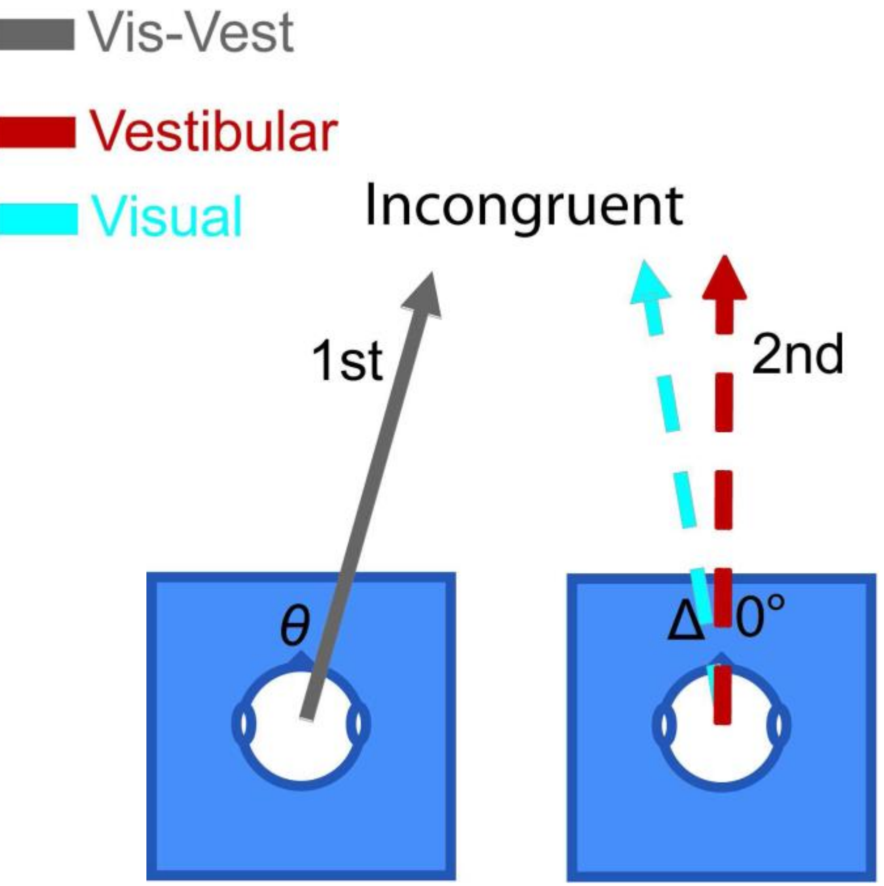
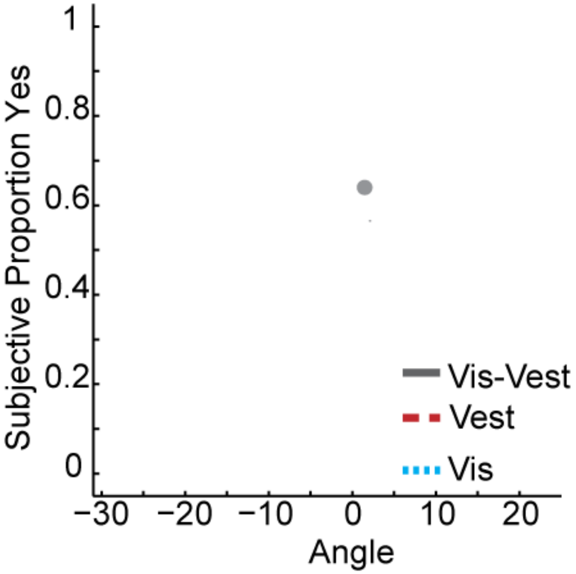
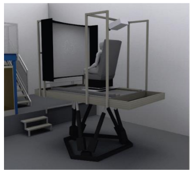
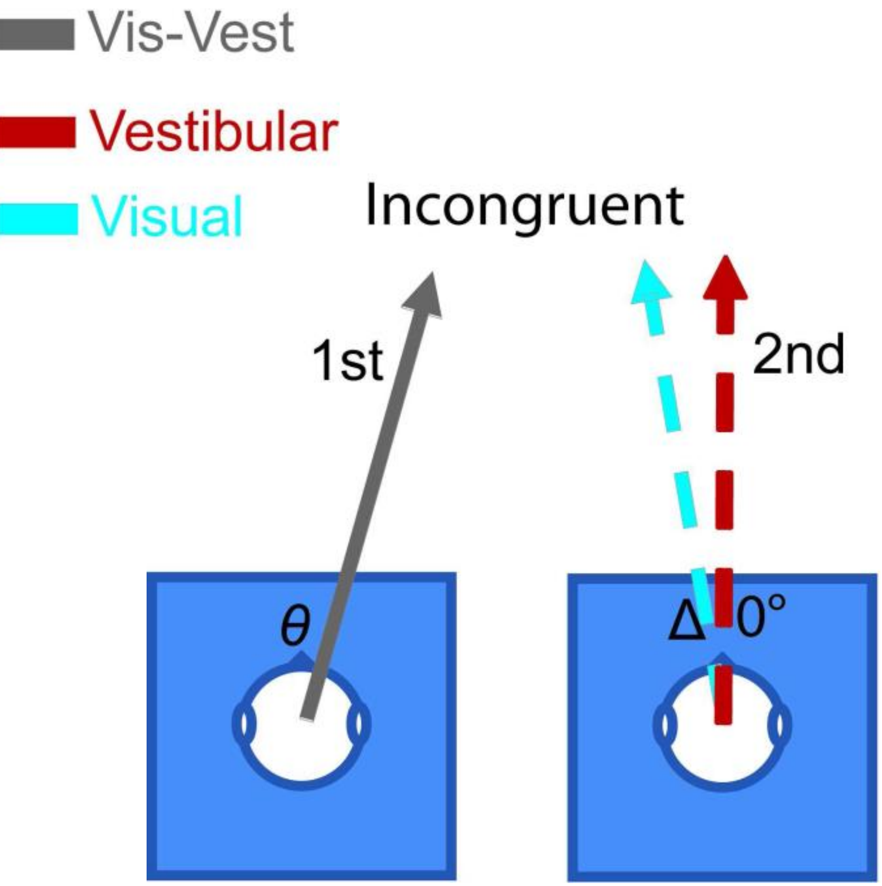
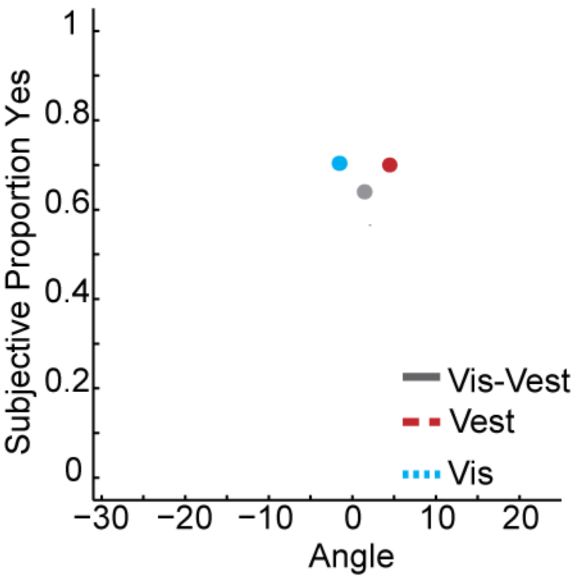


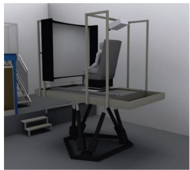




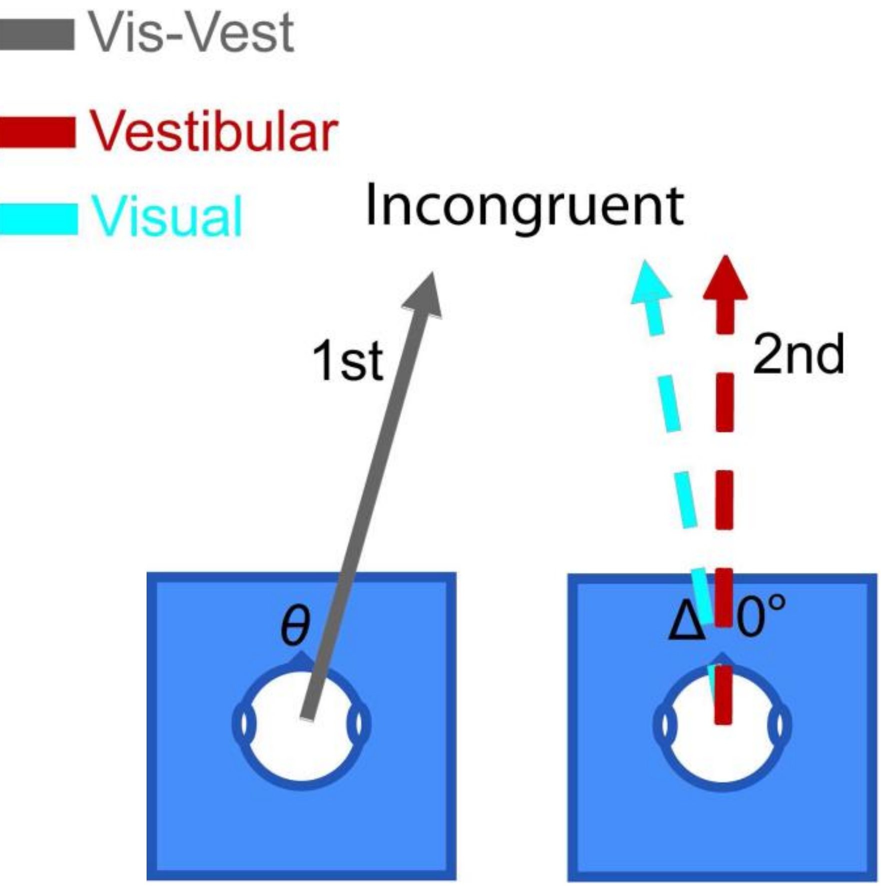
Individual participant analysis

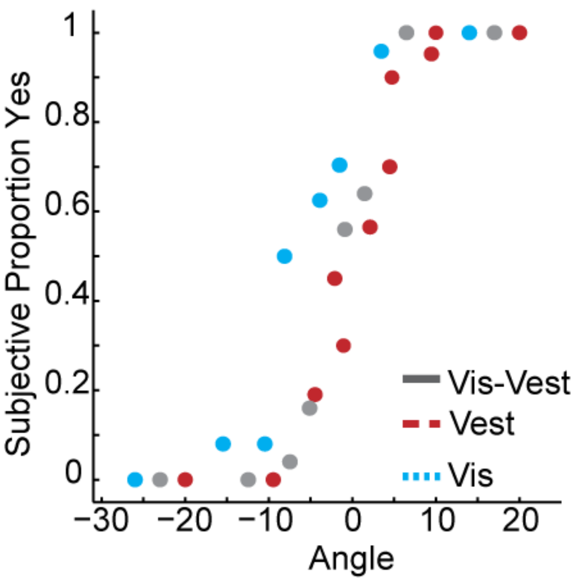


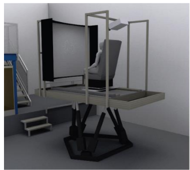




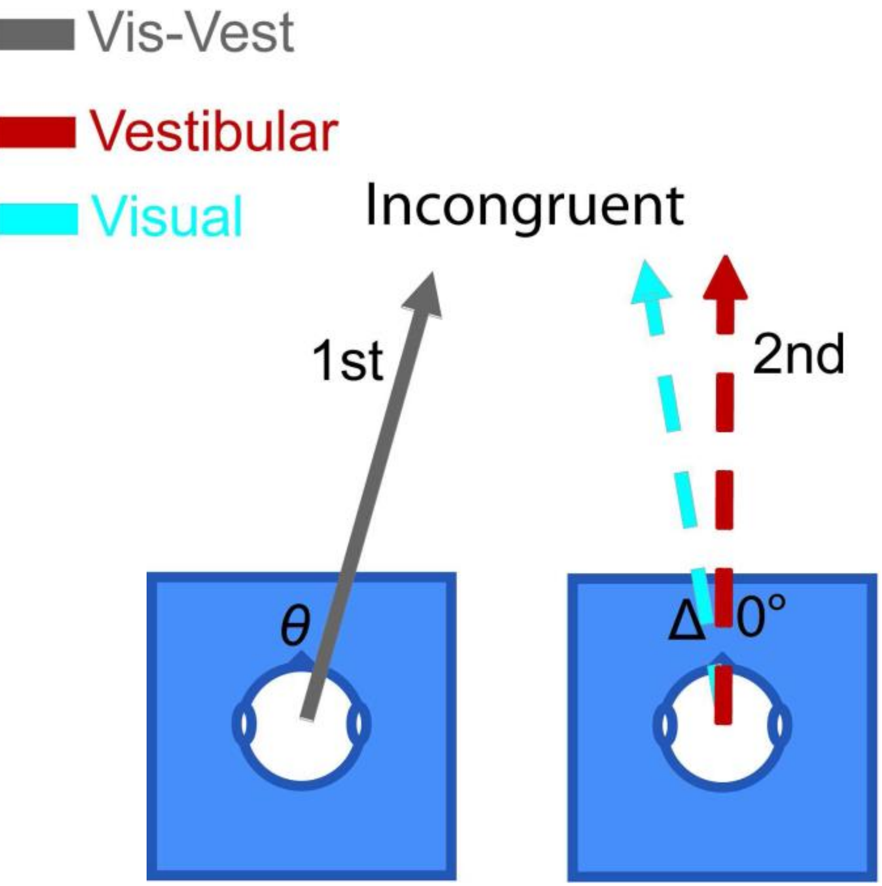
Individual participant analysis

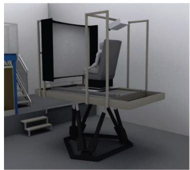






Individual participant analysis



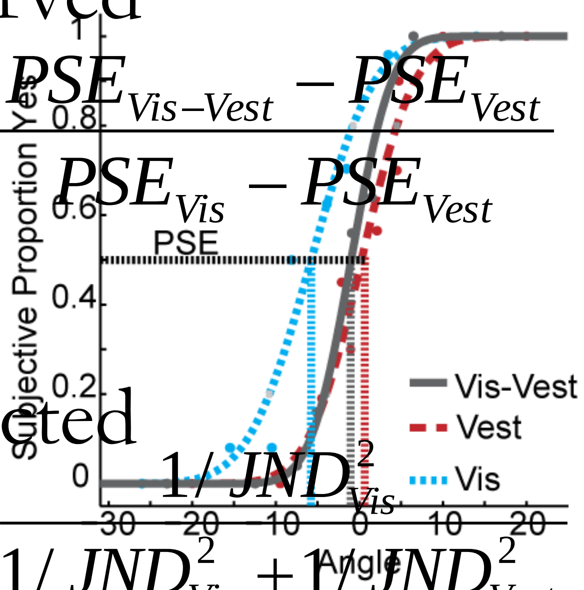


Maximum Likelihood Estimation

$$\widehat{S}_{Vis-Vest} = w_{Vis}\hat{S}_{Vis} + w_{Vest}\hat{S}_{Vest}$$

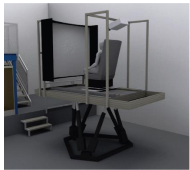
Observed

$$w_{Vis} = \frac{PSE_{Vis-Vest} - PSE_{Vest}}{PSE_{Vis} - PSE_{Vest}}$$



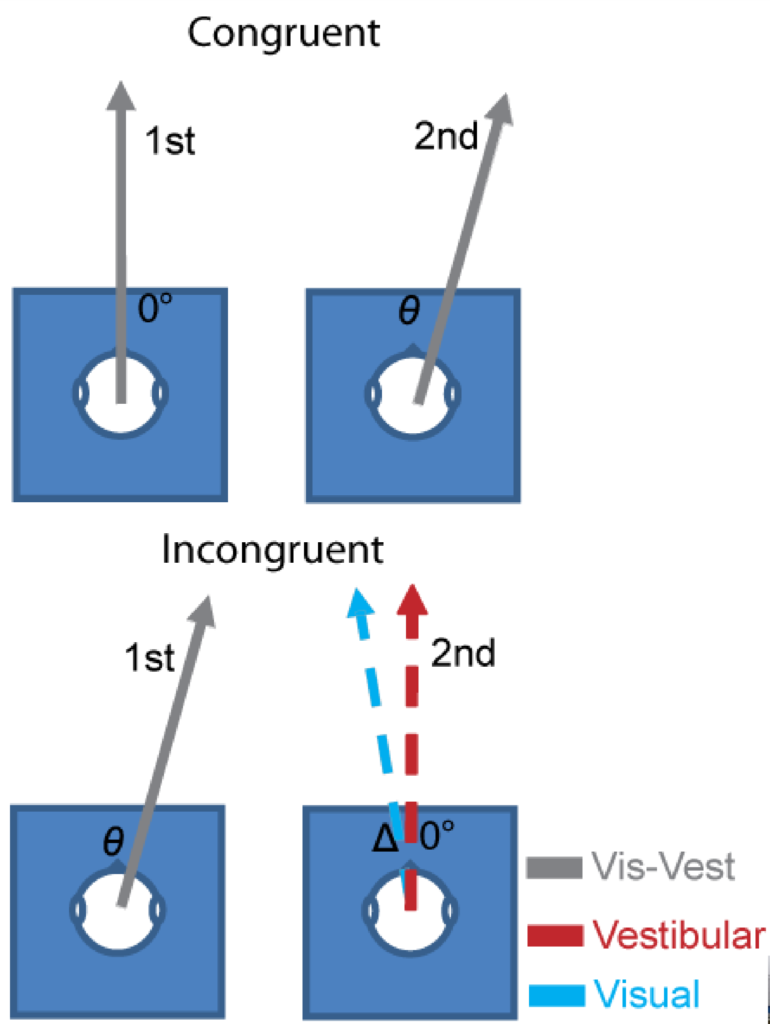
Predicted

$$\hat{w}_{Vis} = \frac{1/JND_{Vis}^2}{1/JND_{Vis}^2 + 1/JND_{Vest}^2}$$

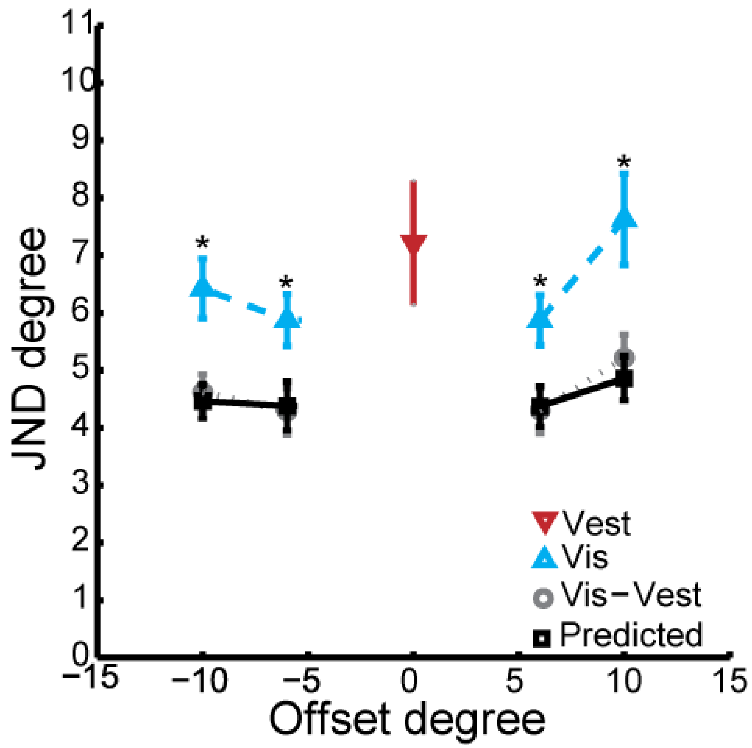


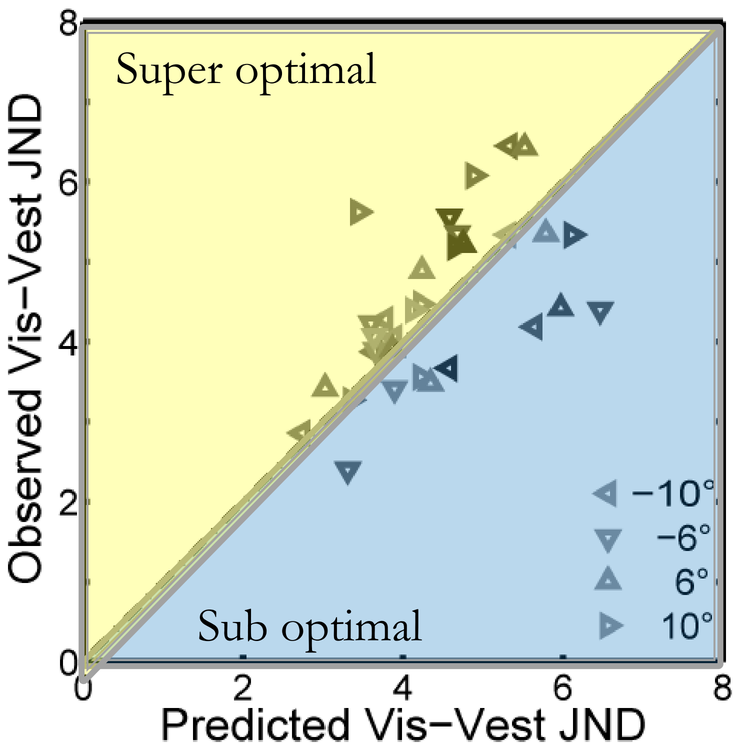
Spatial Conflict

- Conditions
  - 1 Vestibular alone
    - One Standard
    - Θ=0°
  - 4 Visual alone
    - Four standards
    - Θ=±6°, ±10°
  - 4 Visual-vestibular
    - One Standard
    - Θ=0°
    - Four Offset
    - Δ=±6°, ±10°

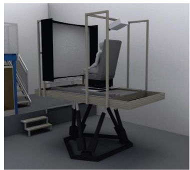


Optimal reduction in variance

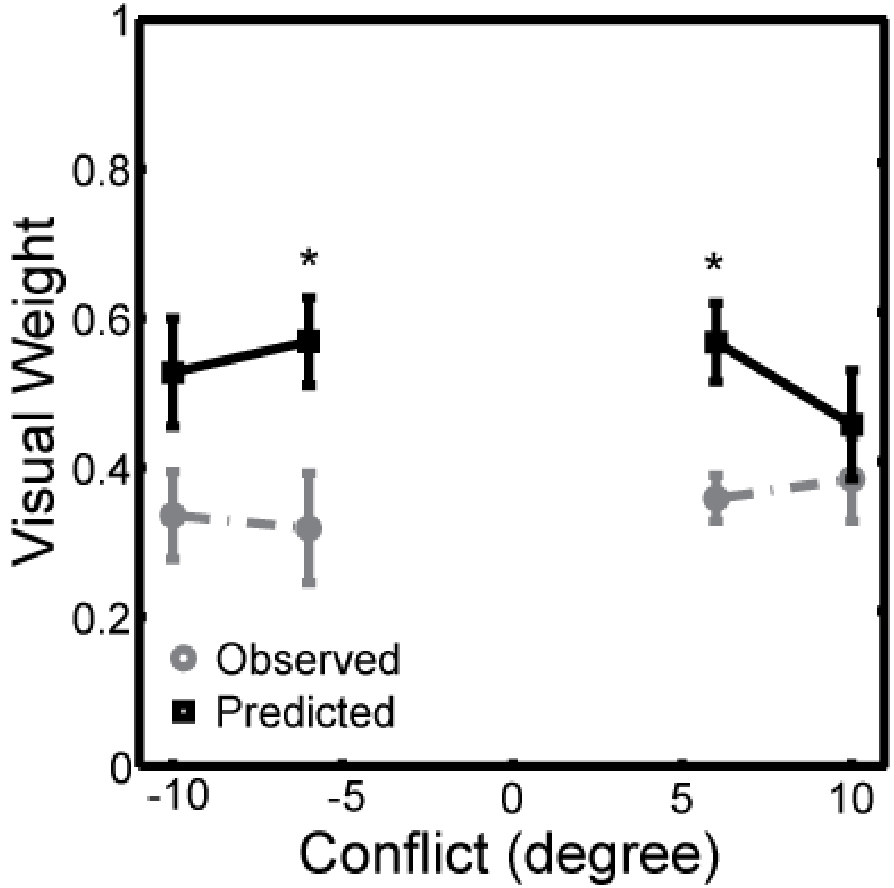




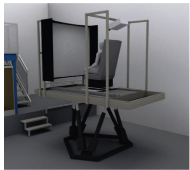
The combination of visual and vestibular cues observe an optimal rule of integration



Weights



The weights are biased towards the vestibular cue

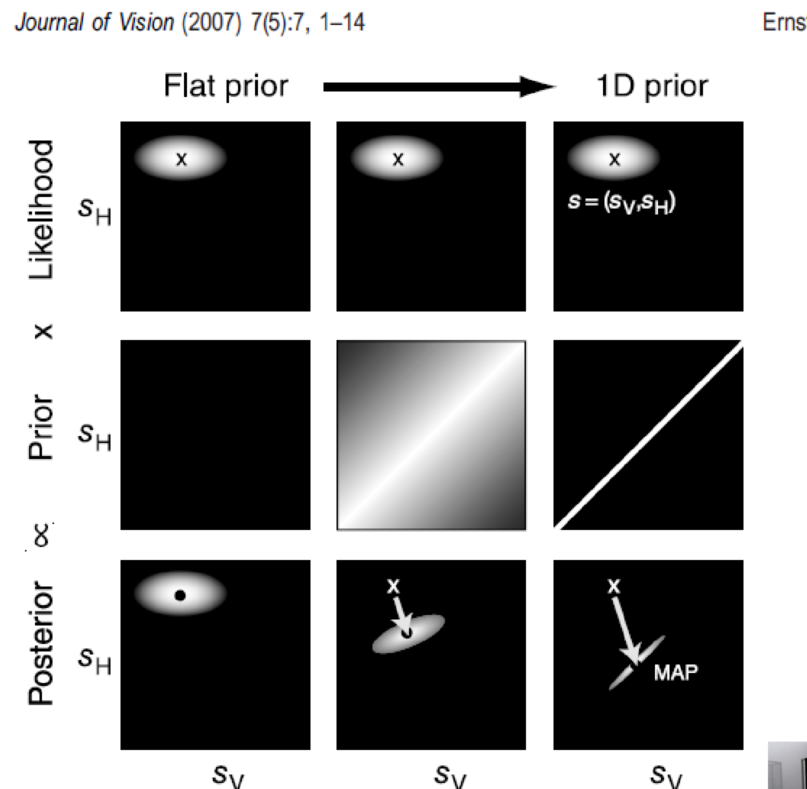


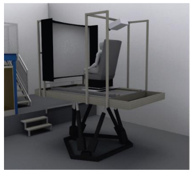
Introduction of a Prior

$$\widehat{S}_{Vis-Vest} = w_{Vis}\hat{S}_{Vis} + w_{Vest}\hat{S}_{Vest} + w_{Prior}\hat{S}_{Prior}$$

$$JND^2_{Vis-Vest} = \frac{1}{1/JND^2_{Vis} + 1/JND^2_{Vest} + 1/JND^2_{Prior}}$$

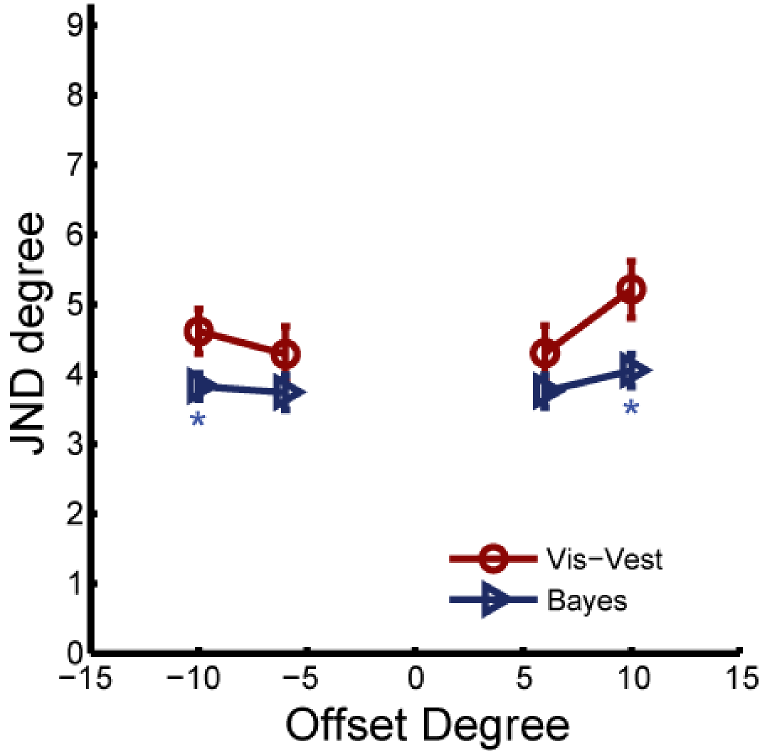
$$w_{Vis} = \frac{1/JND^2_{Vis}}{1/JND^2_{Vis} + 1/JND^2_{Vest} + 1/JND^2_{Prior}}$$



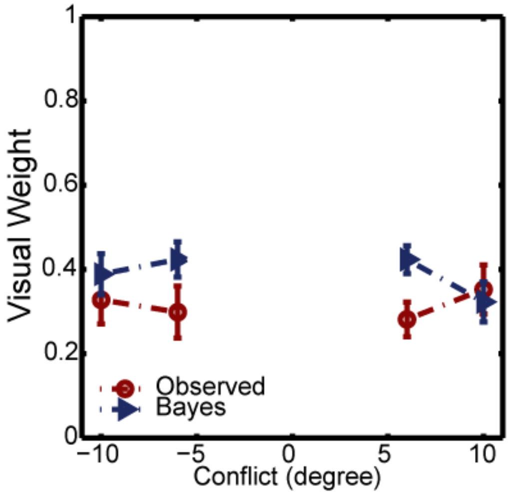


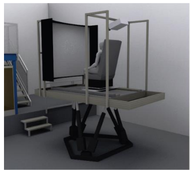
Bayesian Model

ACCURACY



WEIGHTS

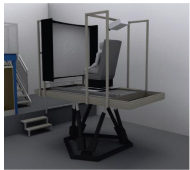




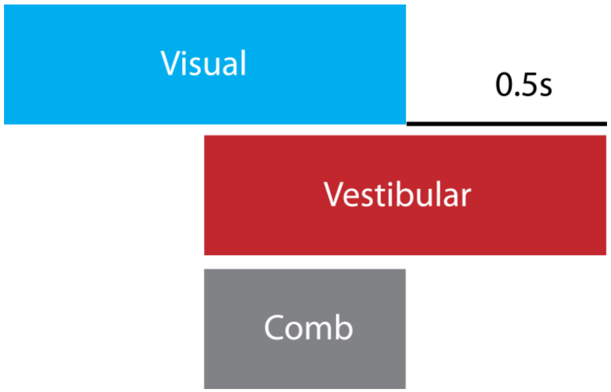
Summary results

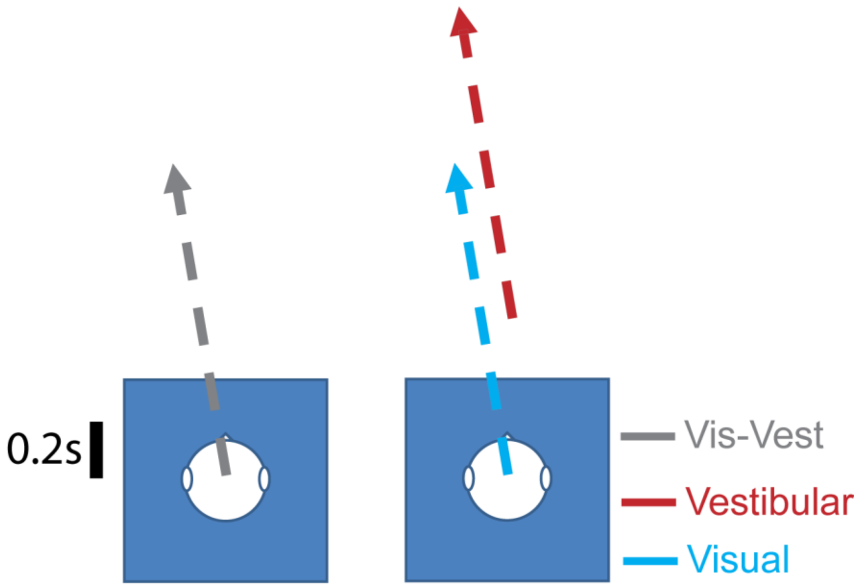
- Participants exhibited a statistically optimal reduction of variance under combined cue conditions.
- Performances in the unimodal conditions did not predict the weights in the combined cue conditions.
- Therefore, we conclude that visual and vestibular cue combination is not predicted solely by the reliability of each individual cue but rather, there is a prior which leads to a higher weighting of vestibular information in this task.

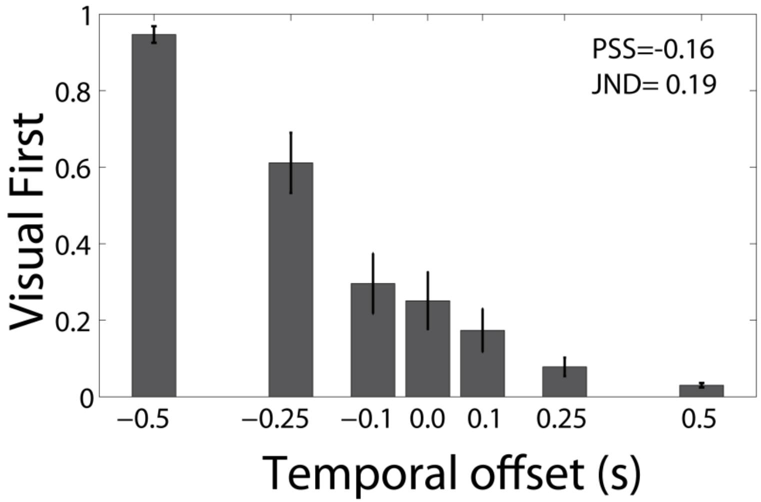
Butler, Smith, Campos, & Bülthoff *Journal of Vision* (2010)

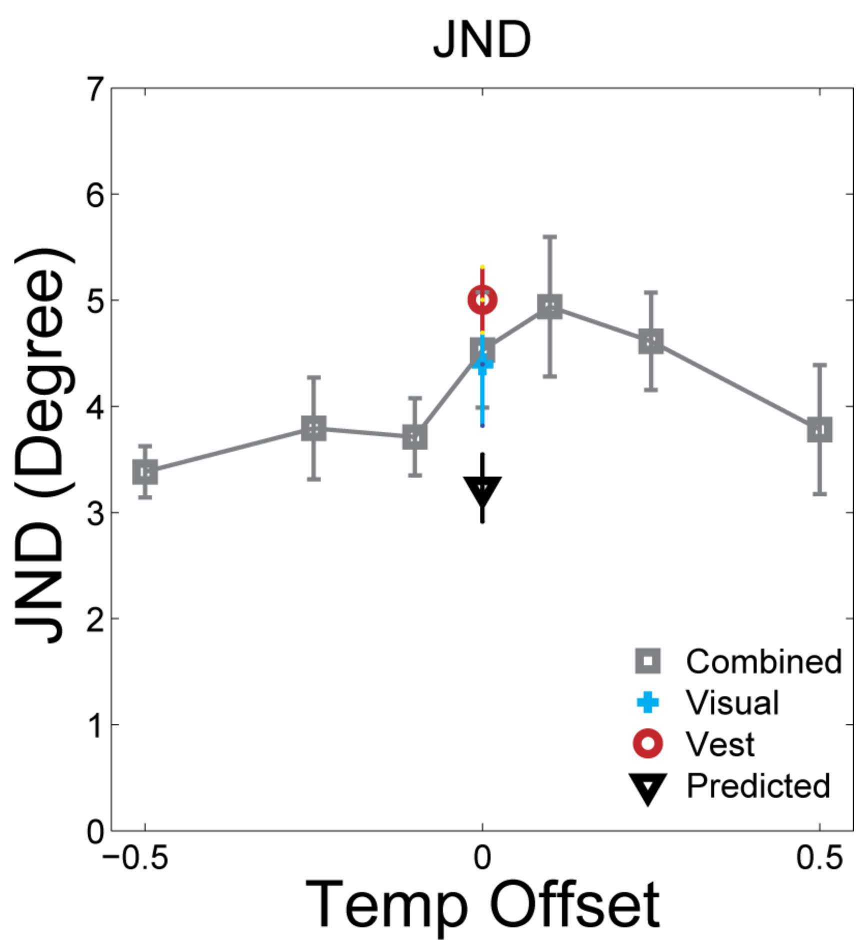


Temporal Conflict





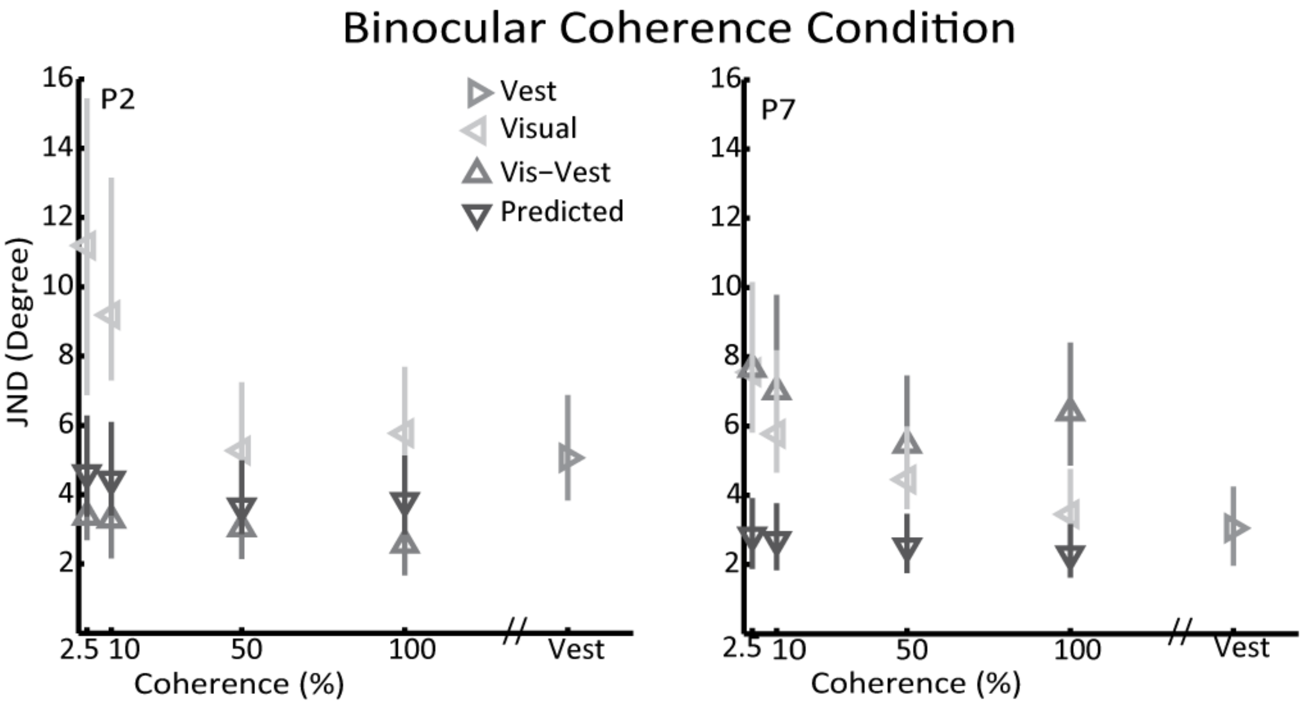




Butler et al (In Prep)

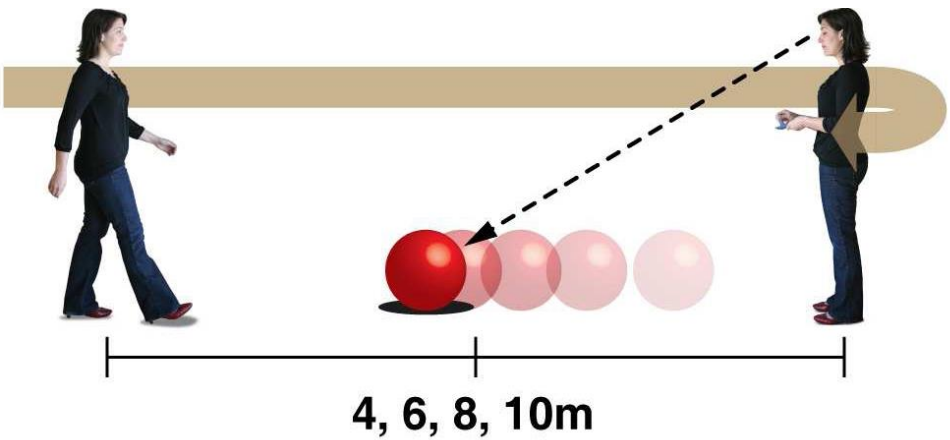
Supplementary

Reproducible nature of result



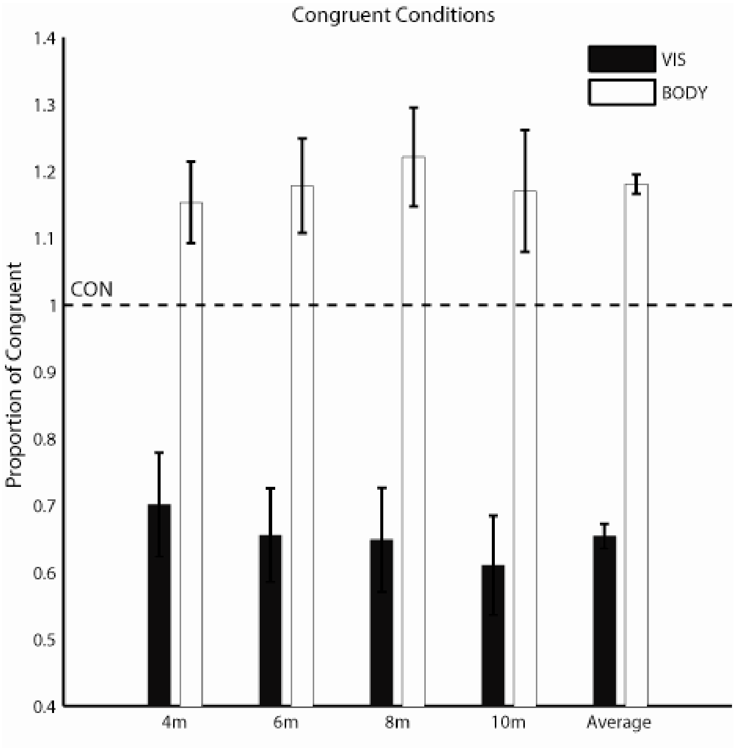
Multisensory integration in the estimation of walked distances

- Conditions
  - Visual Alone
    - 0.7, 1.0, 1.4
  - Body Cues



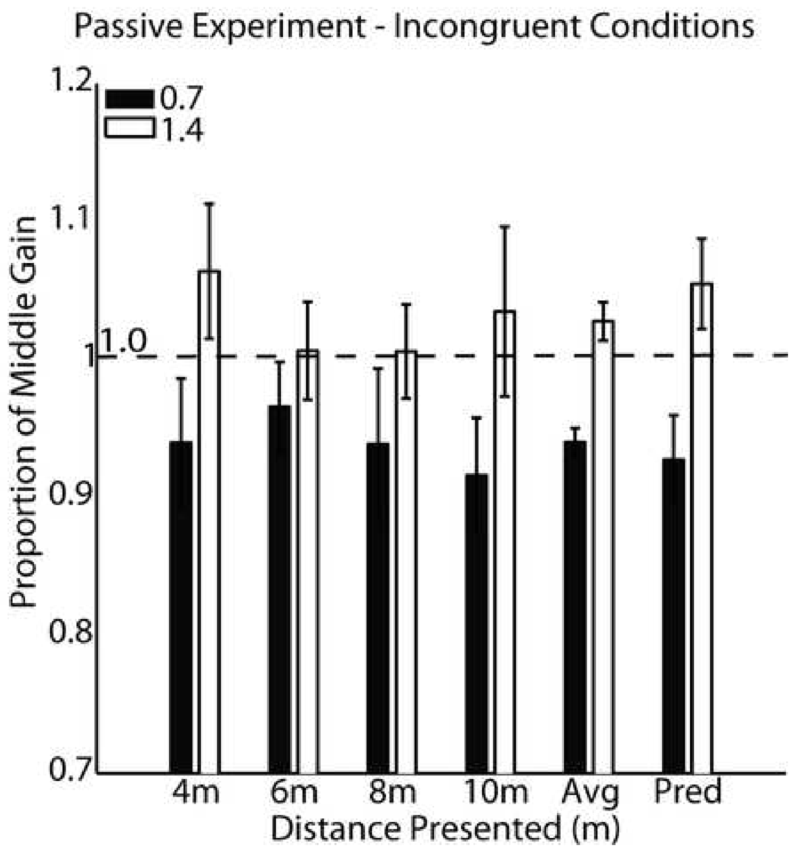
  - Combined
    - Congruent
    - Incongruent Visual Gain (0.7 1.4)
  - 4 distances (4, 6, 8 10m)

Congruent results



- Congruent combined distance estimation sits between visual alone and body based cues

Incongruent Results



- The combined results are predicted by the unisensory results.
- Body based we relied upon more than visual cues
- Within body based cues the vestibular cues were relied upon more than proprioceptive cues

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Conclusion

- The combination of visual and body based cues for walking is predicted by a MLE model