EMHMM: Eye Movement Analysis with Hidden Markov Models

Lecture 1

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Outline

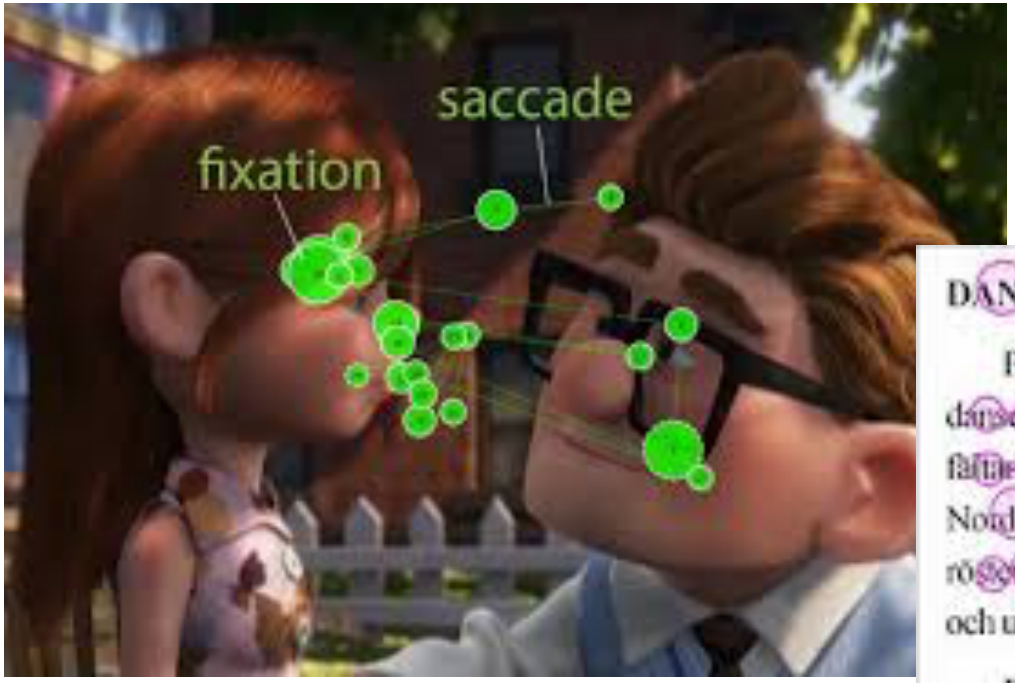
- **Introduction to EMHMM**
  - EMHMM: Example studies
  - EMHMM with co-clustering
  - EMSHMM (Switching HMM)
- **Forming project groups**
- **EMHMM toolbox tutorial**

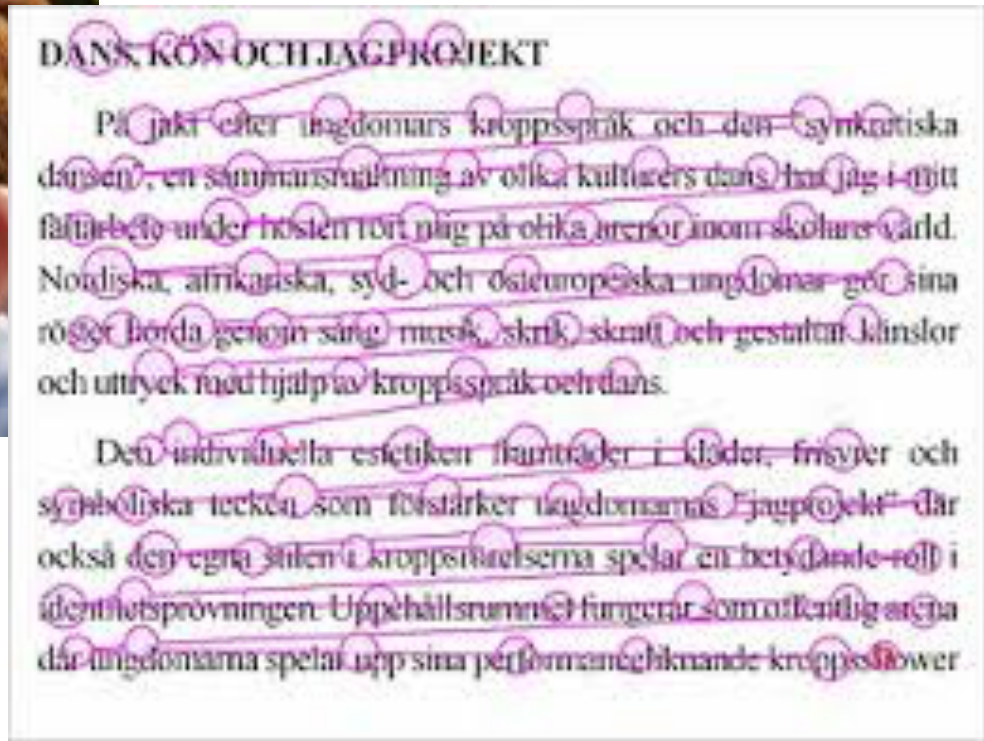
Why are you interested in EMHMM?

- Tell me a bit about your background …

Background

- Fixations and saccades





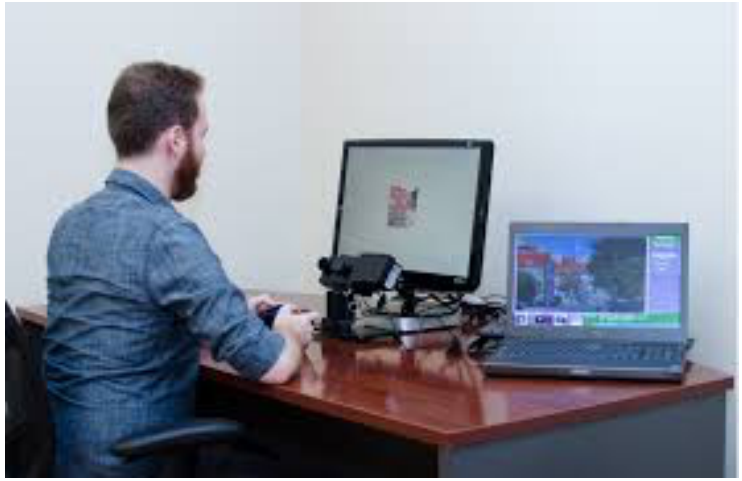
DANS, KÖN OCH JAGPROJEKT

På jakt efter ungdomars kroppsspråk och den synkratiska dansen, en sammanslutning av olika kulturers dans, har jag i mitt fältarbete under hösten rört mig på olika arenor inom skolans värld. Nordiska, afrikanska, syd- och östeuropeiska ungdomar gör sina röster hörda genom sång, musik, skratt, skratt och gestaltar känslor och uttryck med hjälp av kroppsspråk och dans.

Den individuella estetiken framträder i kläder, frisyrer och symboliska tecken som förstärker ungdomarnas "jagprojekt" där också den egna stilen i kroppsrörelserna spelar en betydande roll i identitetsprövningen. Uppehållsrummet fungerar som ett fristående arena där ungdomarna spelar upp sina performanceliknande kroppsflower

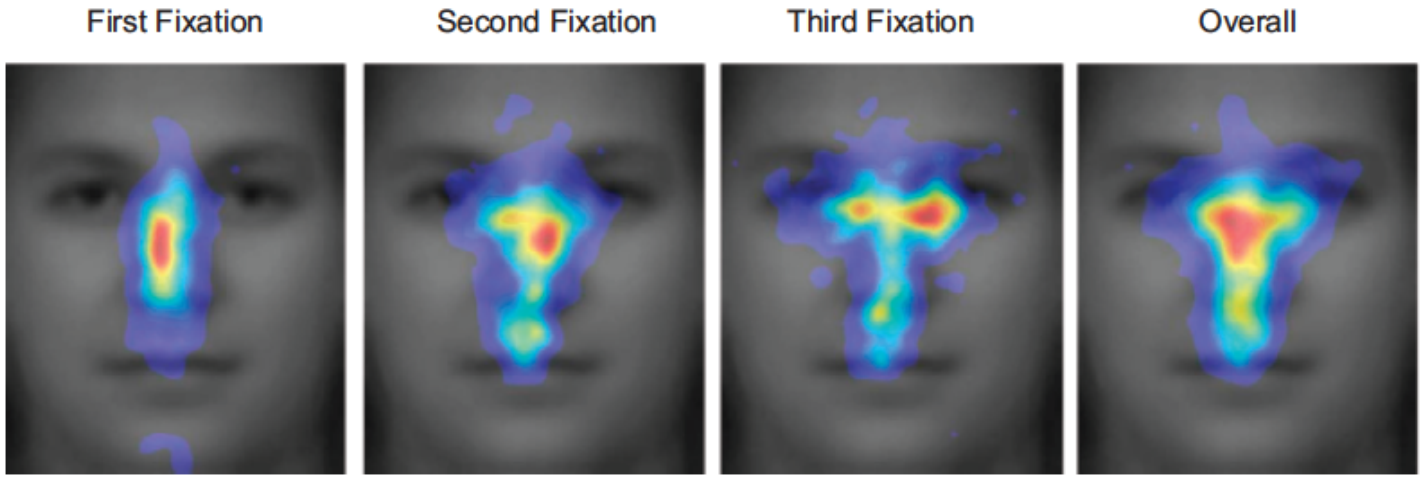
Background

- You need an eye tracker to get eye gaze position information.
- There are programs to help parse eye gaze position data into fixations and saccades.
- EMHMM takes fixation information as input.

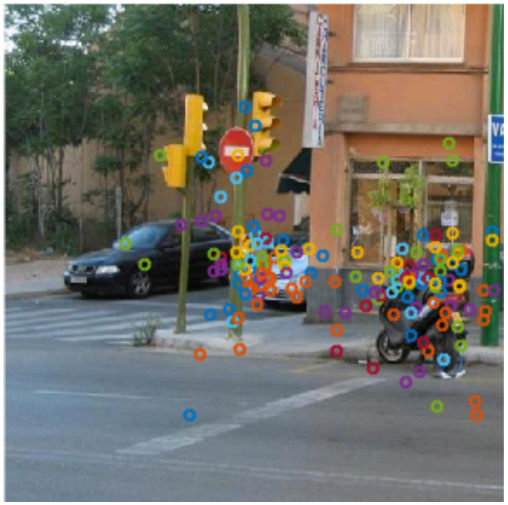


Background

- Eye movement reflects underlying cognitive processes.



(Hsiao & Cottrell, 2008)

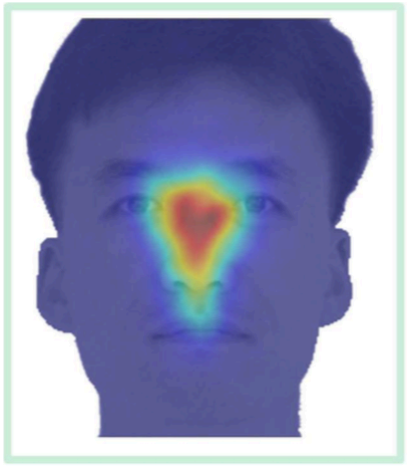


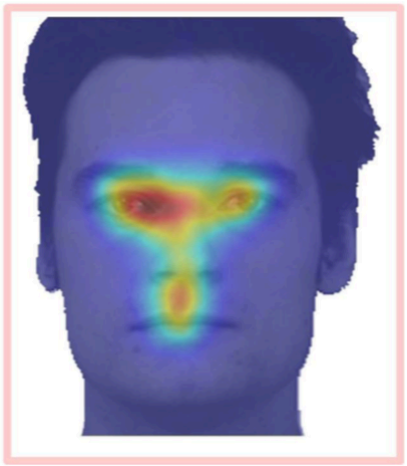
(Coutrot, Hsiao, & Chan, 2018)

Background

- Substantial individual differences in eye movements can indicate differences in strategy or cognitive style.

Website viewing (Eckhardt et al., 2013)

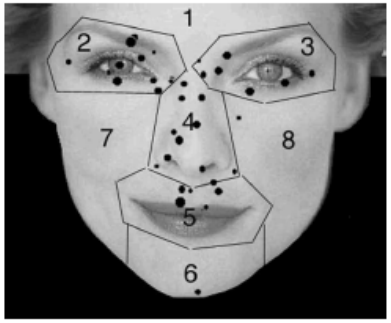


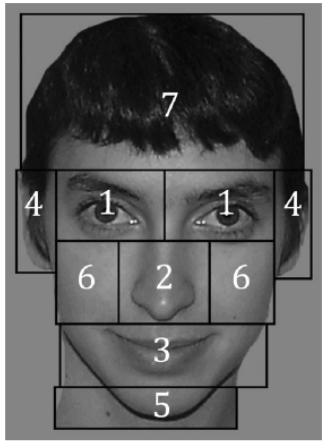


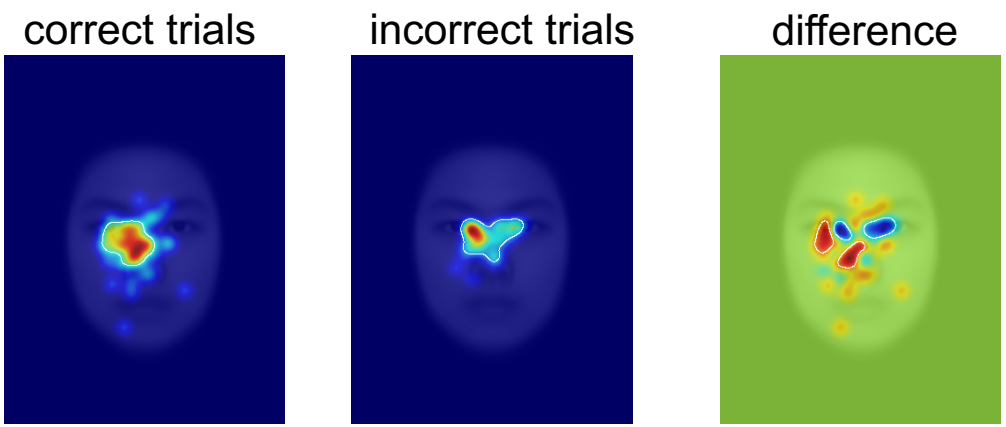
Face recognition (Kelly et al., 2011)

Eye Movement Analysis

- **Most of the current eye movement analysis methods Do not adequately reflect individual differences:**
  - Regions of Interest (ROI) (e.g. Barton et al. 2006; Goldberg & Helfman, 2010)
    Problem: ROIs are inconsistent across studies; it does not reflect individual difference in ROI choices
  - Heat map approach (iMap, Caldara & Miellet, 2011)
    Problems: Difference maps can be hard to interpret; it does not handle transition information between ROIs

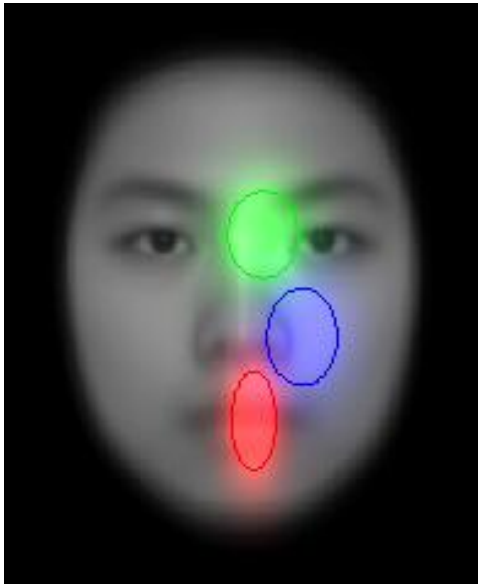






Eye Movement analysis with Hidden Markov Models (EMHMM)

- **EMHMM (Chuk, Chan, & Hsiao, 2014) summarizes a person's eye movement pattern using personalized ROIs and transitions among the ROIs**

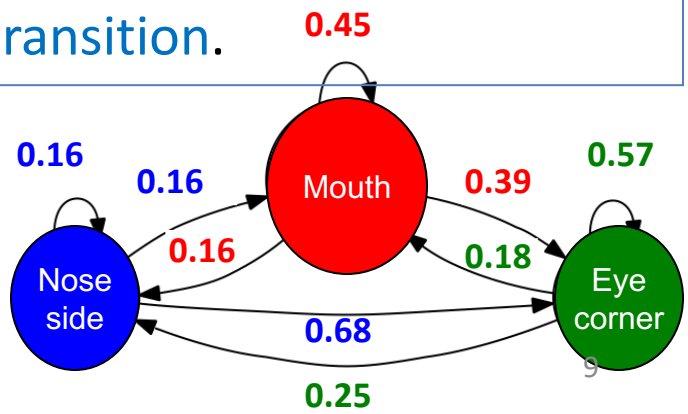


The ellipses show the ROIs as 2-D Gaussian emissions; number of ROIs is automatically determined using Bayesian methods.

The prior values indicate the probabilities that a fixation sequence starts from the ellipses.

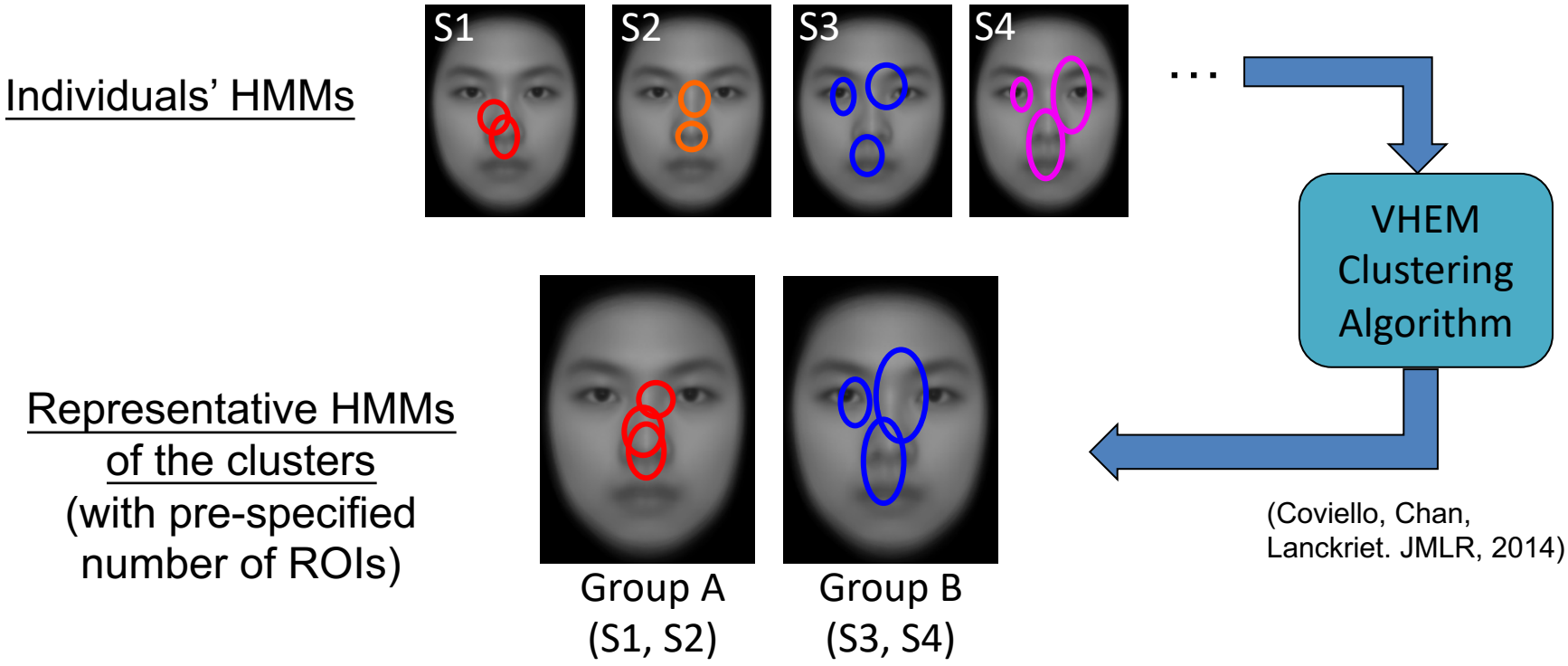
The transition probabilities indicate the probabilities of observing a particular transition.

	to red	to green	to blue
prior	.23	.58	.19
from red	.45	.39	.16
from green	.18	.57	.25
from blue	.16	.68	.16



EMHMM: Clustering

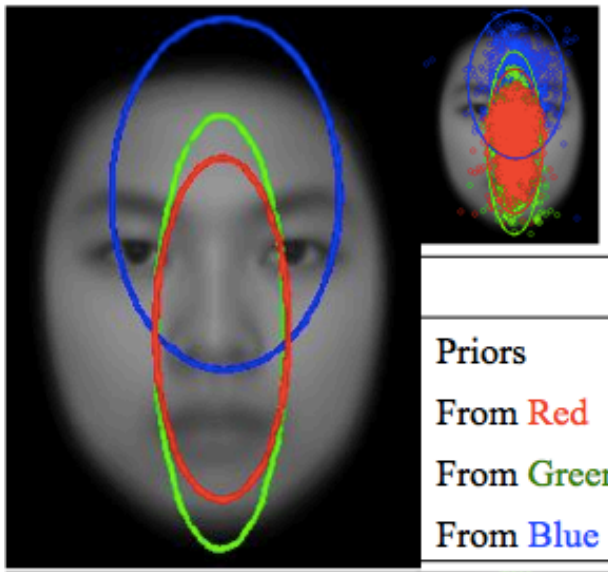
- **A data-driven approach to discover common strategies:**
  - Representative HMMs of common strategies
  - Log likelihood measures to quantify eye movement pattern similarities

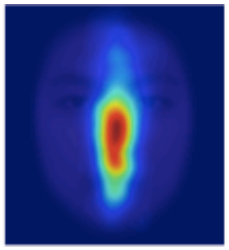


Chuk, T., Chan, A. B., & Hsiao, J. H. (2014). Understanding eye movements in face recognition using hidden Markov models. *Journal of Vision*, *14*(11):8, 1-14.

Example of EMHMM Clustering

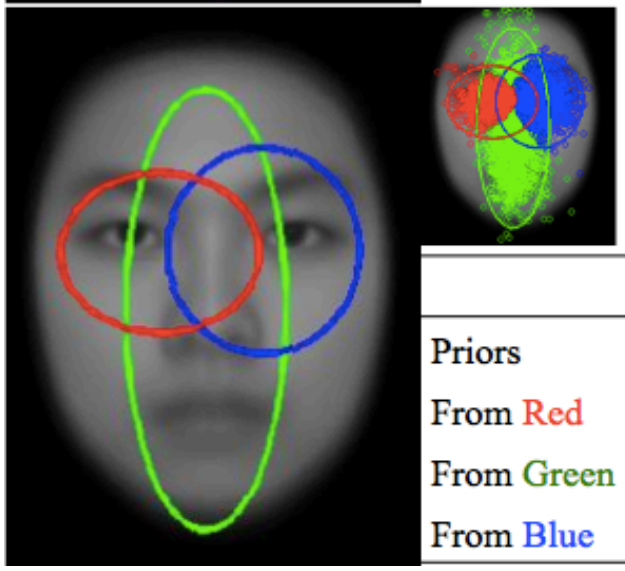
- 34 young and 34 older adults performed a face recognition task.
- We clustered individual HMMs into 2 groups.

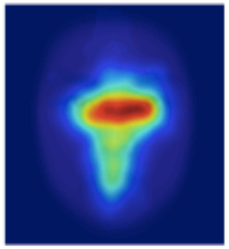




Holistic

	To Red	To Green	To Blue
Priors	.16	.80	.04
From Red	.82	.12	.06
From Green	.93	.02	.05
From Blue	.07	.00	.93





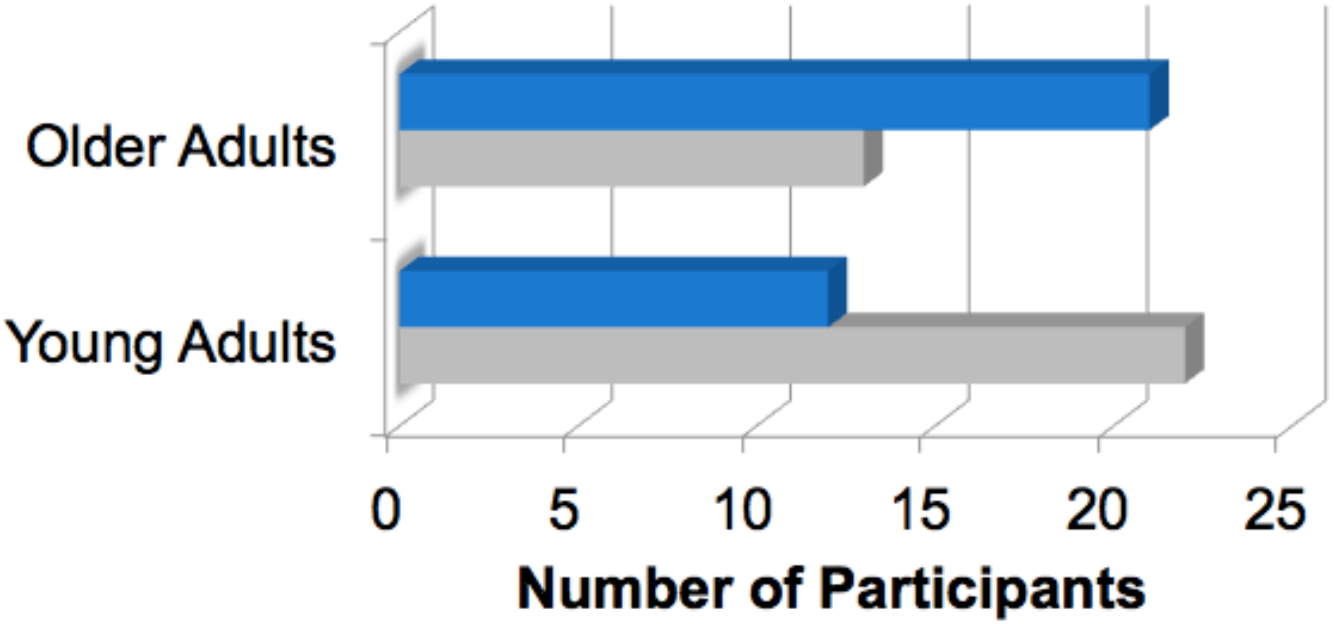
Analytic

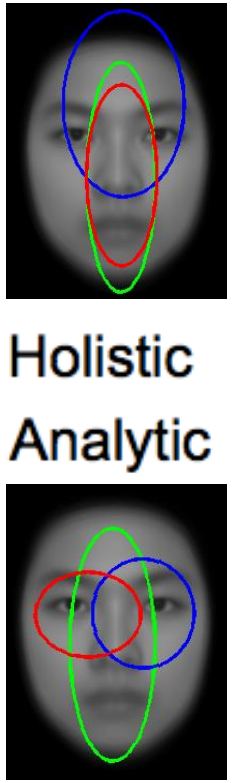
	To Red	To Green	To Blue
Priors	.03	.82	.15
From Red	.21	.34	.45
From Green	.25	.36	.39
From Blue	.27	.26	.47

Chan, C. Y. H., Chan, A. B., Lee, T. M. C., & Hsiao, J. H. (2018). Eye movement patterns in face recognition are associated with cognitive decline in older adults. *Psychonomic Bulletin & Review, 25*(6), 2200-2207.

Example of EMHMM Clustering : age difference

- **More older adults adopted holistic patterns while more young adults adopted analytic patterns**, X(2) = 4.77, p = .03 (Chi-square test)

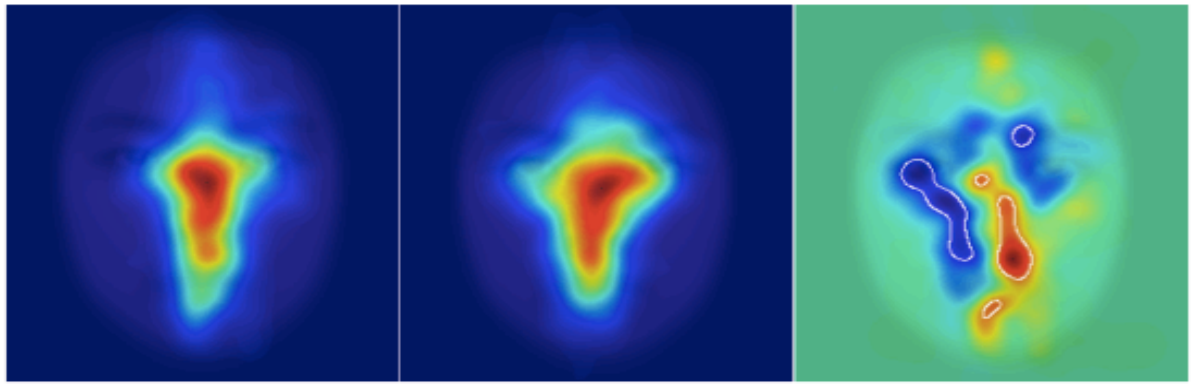




Example of EMHMM Clustering : Traditional group comparison vs. EMHMM

- **Individual differences are obscured in direct group comparisons**

Traditional Age group comparison

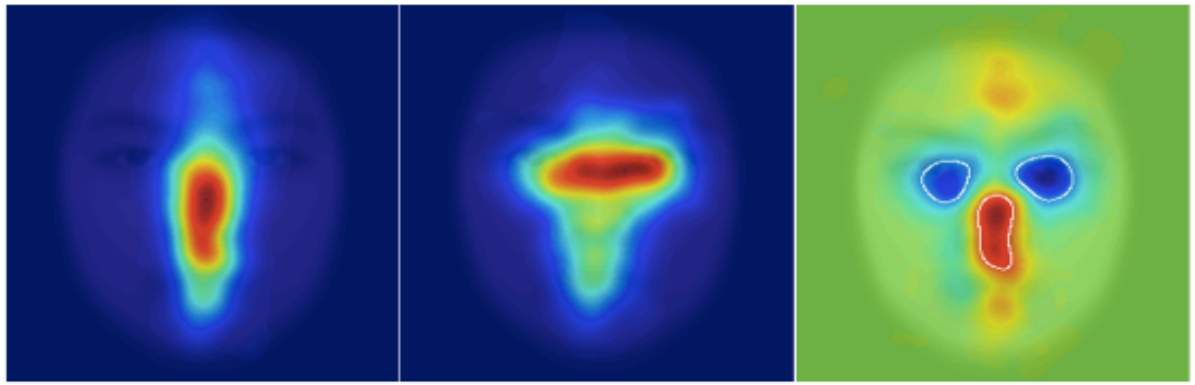


a) Older adults group | b) Young adults group | c) Difference (Old – Young)

Old

Young

HMM subgroup comparison



d) Holistic pattern group | e) Analytic pattern group | f) Difference (Holistic – Analytic)

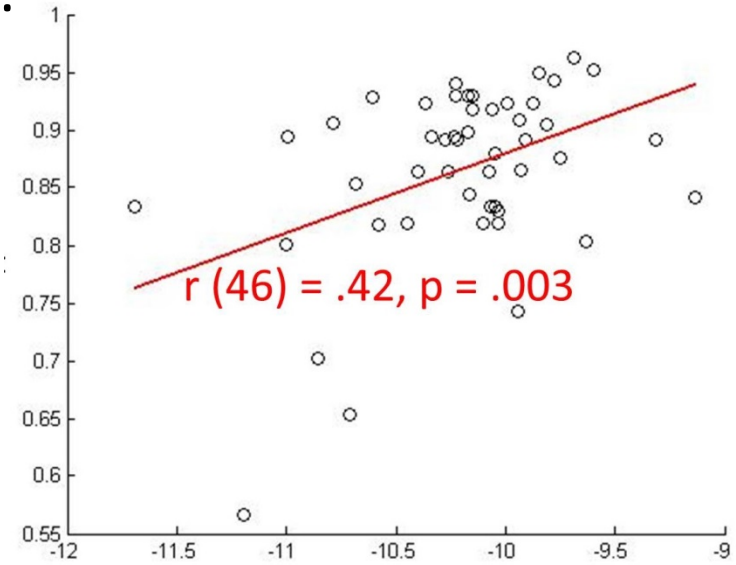
Holistic

Analytic

Example of Similarity Measures

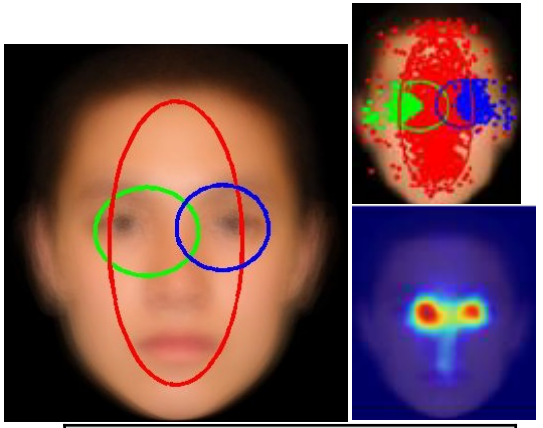
- We can quantify the *similarity* of a participant's eye movement pattern to a common strategy using log-likelihood measures.
- E.g., Examine the correlation between the similarity and performance .

Recognition performance (A')



Log-likelihood of being analytic

less analytic ⟷ *more analytic*



	to red	to green	to blue
prior	.79	.14	.07
from red	.39	.38	.23
from green	.25	.09	.66
from blue	.29	.62	.09

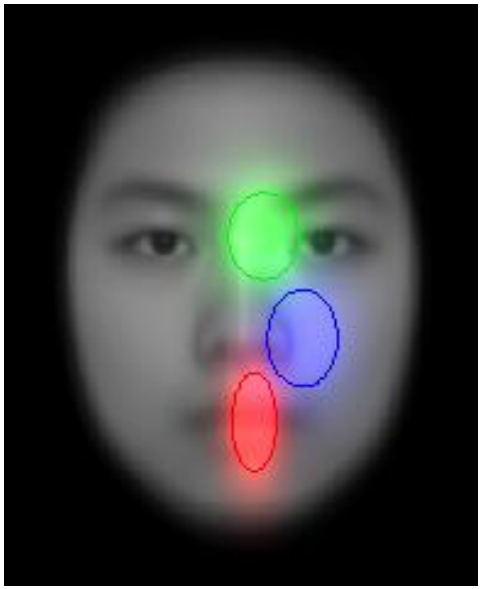
- **EMHMM is particularly suitable for examining the link between eye movement patterns and other measures.**

Chuk, T., Crookes, K., Hayward, W. G., Chan, A. B., & Hsiao, J. H. (2017). Hidden Markov model analysis reveals the advantage of analytic eye movement patterns in face recognition across cultures. *Cognition*, *169*, 102-117.

EMHMM Summary

Feature 1: Generate Individual HMMs

- Personalized regions of interest (ROIs)
- Transition probabilities among the ROIs



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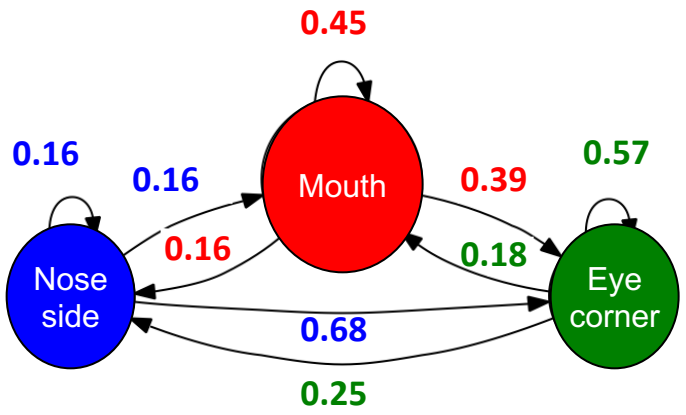

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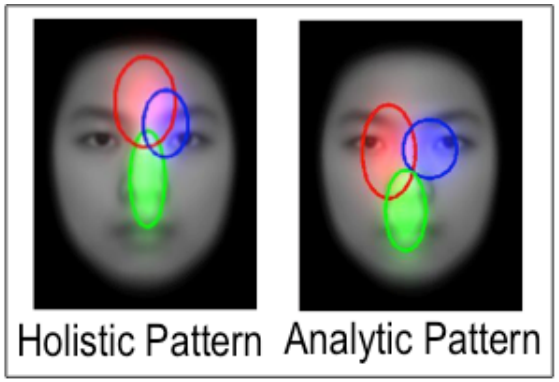
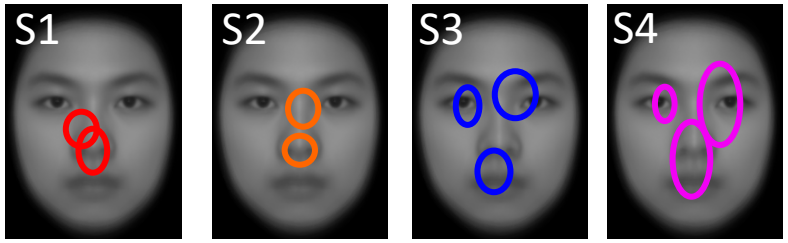
EMHMM Summary

Feature 2:
Discover Common Patterns through Clustering



(Chuk, Chan, & Hsiao, 2014)

Individuals' HMMs



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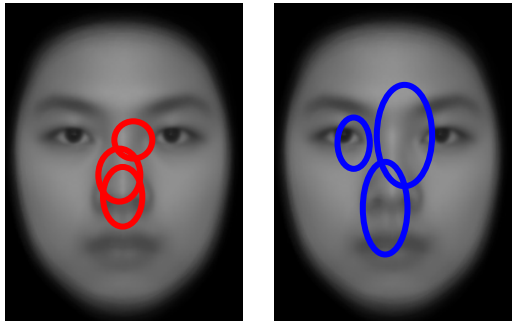
VHEM Clustering Algorithm

Representative HMMs of the clusters



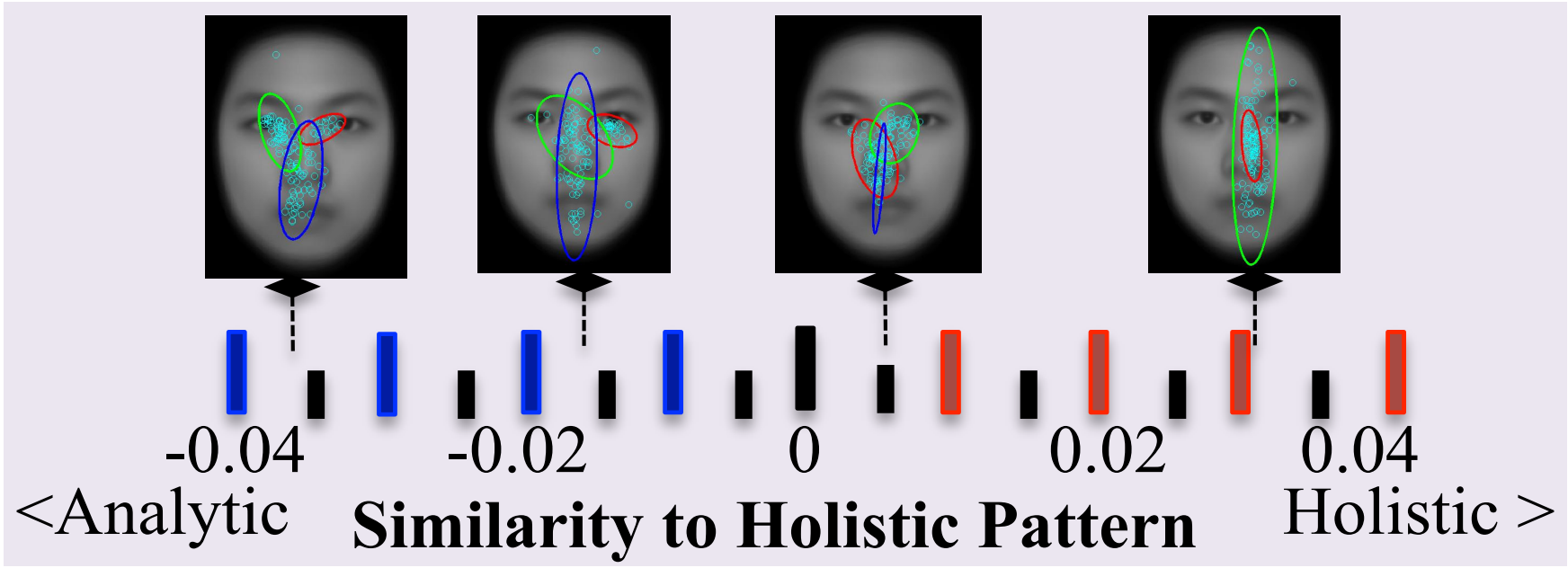
Group A (S1, S2)

Group B (S3, S4)

(Coviello, Chan, Lanckriet. JMLR, 2014)

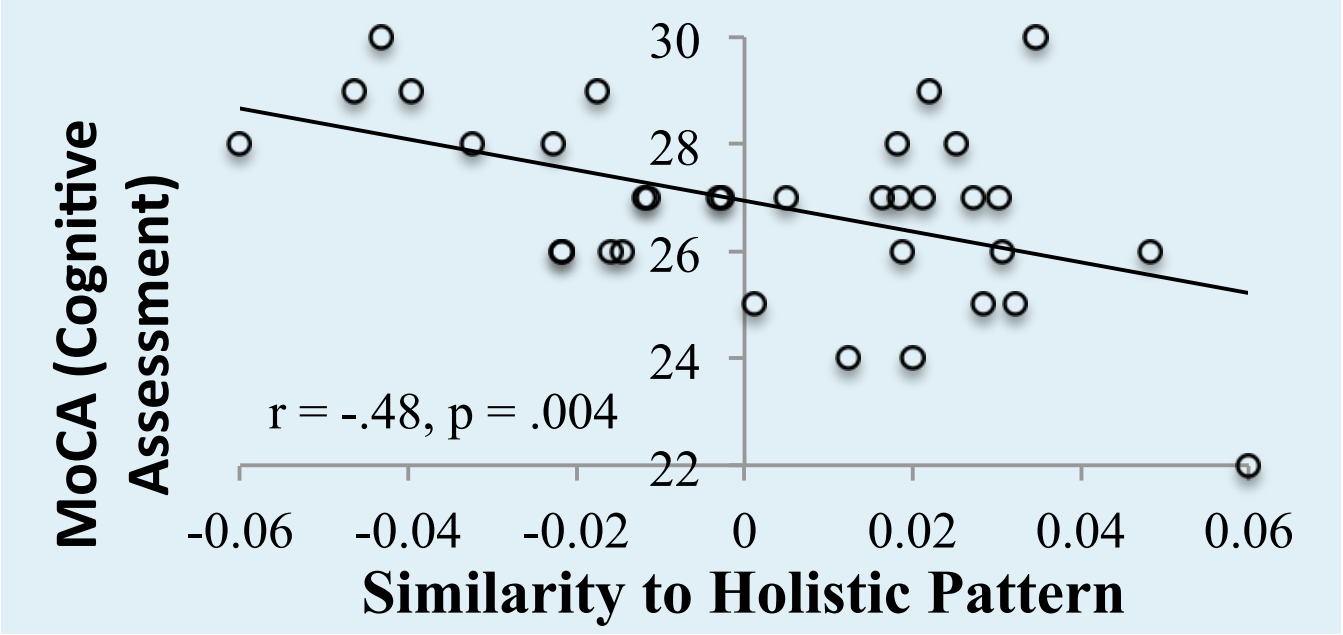
EMHMM Summary

Feature 3: Quantify Similarity between Patterns (Using Data Log-Likelihoods)



EMHMM Summary

Feature 4:
Use the Similarity Measure to Examine the Relationship between Eye Movement Patterns and Other Measures



EMHMM: Example studies

- Face learning vs. face recognition
- Eye movement & cognitive ability
- Insomnia and facial expression recognition
- Eye movement & comprehension of documentaries

Face learning vs. face recognition

- **Scan path theory**: Eye movements produced during learning have to be repeated during recognition for the recognition to be successful (Noton & Stark, 1971a; 1971b).
  - Yes: Eye movements during recognition resembled those generated during learning (e.g., Laeng and Teodorescu, 2002: Caldara et al., 2010)
  - No: An exact repetition of eye movements during learning was not necessary for successful recognition (Henderson et al., 2005)
  - Problem: It was unclear how to quantitatively measure eye movement pattern similarity.

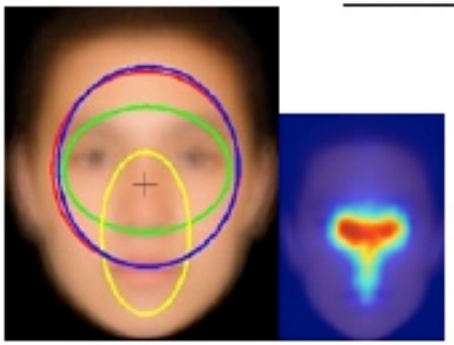
- **Is the similarity between eye movement patterns in face learning and recognition related to recognition performance?**

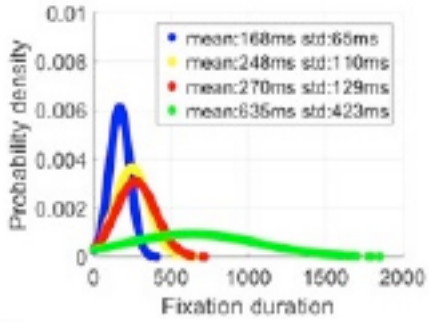
Chuk, T., Chan, A. B., & Hsiao, J. H. (2017). Is having similar eye movement patterns during face learning and recognition beneficial for recognition performance? Evidence from hidden Markov modeling. *Vision Research*, *141*, 204-216.

Face learning vs. face recognition: EMHMM Clustering

- **ROI with fixation duration (ROID)**
- Each participant had 2 models (for learning and recognition phase respectively). We clustered all models to discover common patterns.

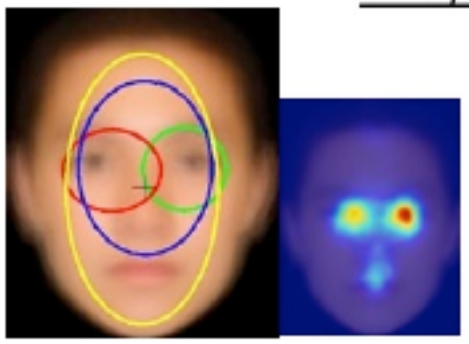
Holistic Pattern

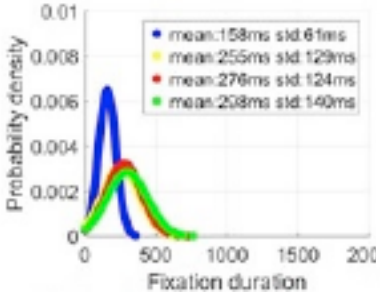




	To Blue	To Yellow	To Red	To Green
Priors	.47	.08	.43	.02
From Blue	.30	.11	.56	.03
From Yellow	.11	.34	.52	.03
From Red	.03	.09	.79	.09
From Green	.02	.06	.58	.34

Analytic Pattern





	To Blue	To Yellow	To Red	To Green
Priors	.66	.23	.05	.06
From Blue	.22	.15	.27	.36
From Yellow	.11	.55	.14	.20
From Red	.05	.29	.12	.54
From Green	.10	.41	.37	.12

Face learning vs. face recognition Results

- **About 40% of the participants used different patterns between face learning and recognition** ($\chi^2(1) = 2.08$, $p = .15$)

Pattern switch		*recognition phase*		
		same	different	**Total**
learning	holistic	18	17	**35**
phase	analytic	11	2	**13**
Total		**29**	**19**	**48**

- Participants who used same or different patterns between learning and recognition did not differ significantly in recognition performance, t(46) = .36, p = .72 .
- Participants who used analytic patterns had better recognition performance than those using holistic patterns (Learning phase pattern, t(46) = 2.24, p = .03; Recognition phase pattern, t(46) = 3.13, p = .003)

Face learning vs. recognition: Summary

- Perceptuomotor memory elicited by eye movement patterns during learning does not play an important role in recognition.

- In contrast, the retrieval of diagnostic information for recognition, such as the eyes for face recognition, is a better predictor for recognition performance.

Chuk, T., Chan, A. B., & Hsiao, J. H. (2017). Is having similar eye movement patterns during face learning and recognition beneficial for recognition performance? Evidence from hidden Markov modeling. *Vision Research*, *141*, 204-216.

EMHMM: Example studies

- Face learning vs. face recognition
- Eye movement & cognitive ability
- Insomnia and facial expression recognition
- Eye movement & comprehension of documentaries

Eye movement & cognitive ability

- **Do eye movement patterns in face recognition reflect cognitive ability? We examined cognitive decline in older adults.**

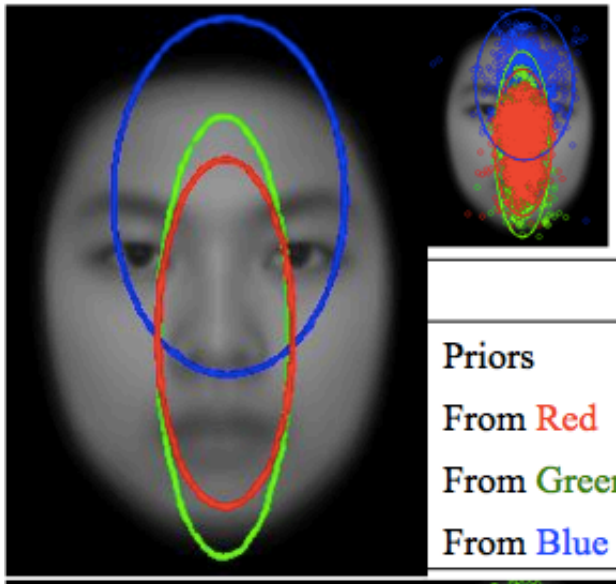
- 34 young and 34 older adults recognized 20 learned faces among 20 new faces.

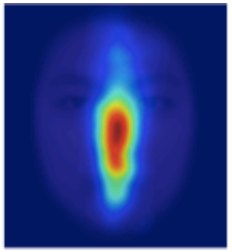
- Older adults' cognitive ability was assessed by the Montreal Cognitive Assessment (MoCA) Hong Kong version (Wong et al., 2009)

Chan, C. Y. H., Chan, A. B., Lee, T. M. C., & Hsiao, J. H. (2018). Eye movement patterns in face recognition are associated with cognitive decline in older adults. *Psychonomic Bulletin & Review, 25(6), 2200-2207.*

Eye movement & cognitive ability: EMHMM Clustering

- Cluster all individual HMMs into 2 clusters





Holistic

	To Red	To Green	To Blue
Priors	.16	.80	.04
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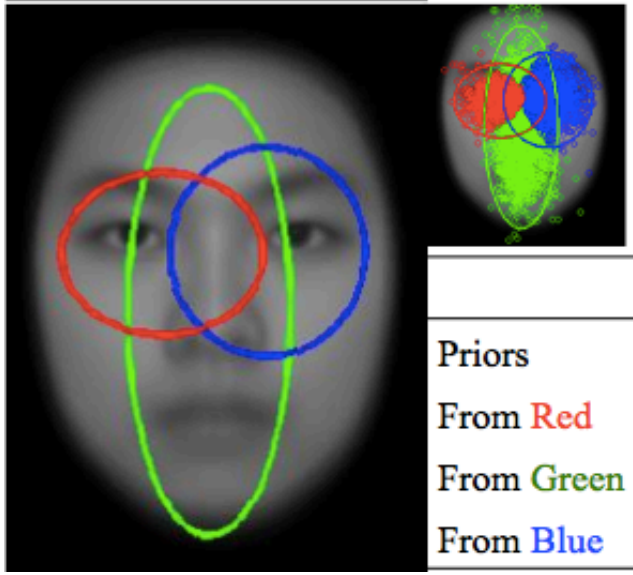

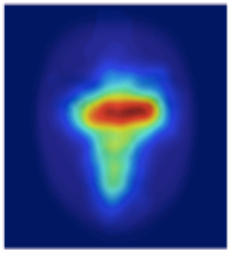

Analytic

	To Red	To Green	To Blue
Priors	.03	.82	.15
From Red	.21	.34	.45
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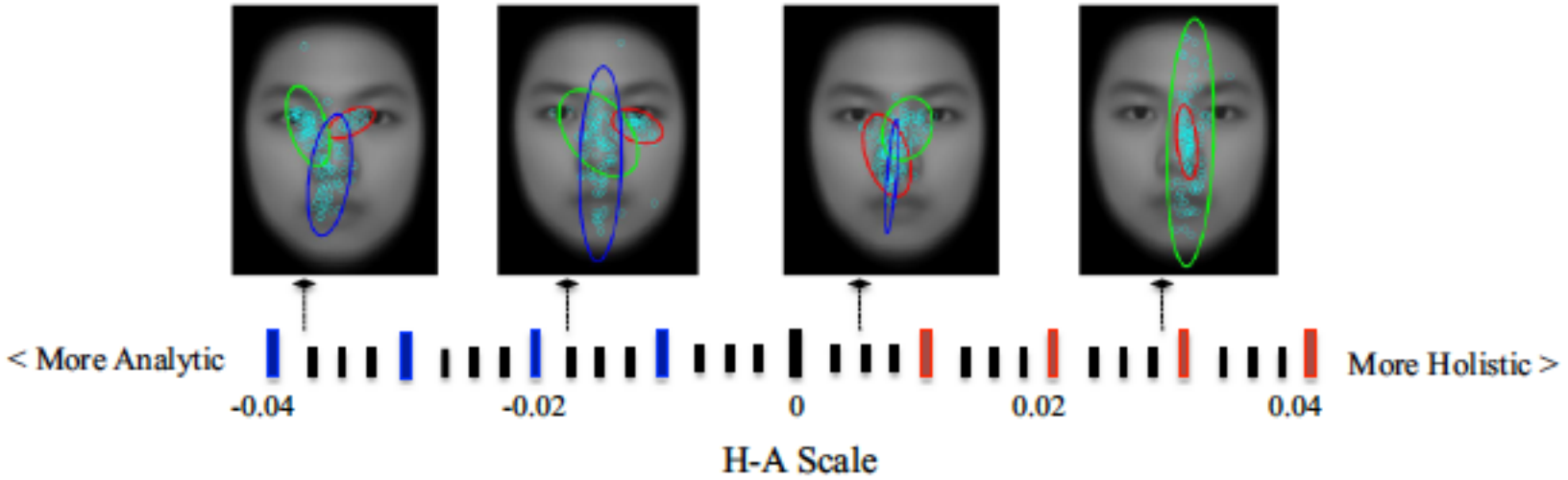
From Blue	.27	.26	.47

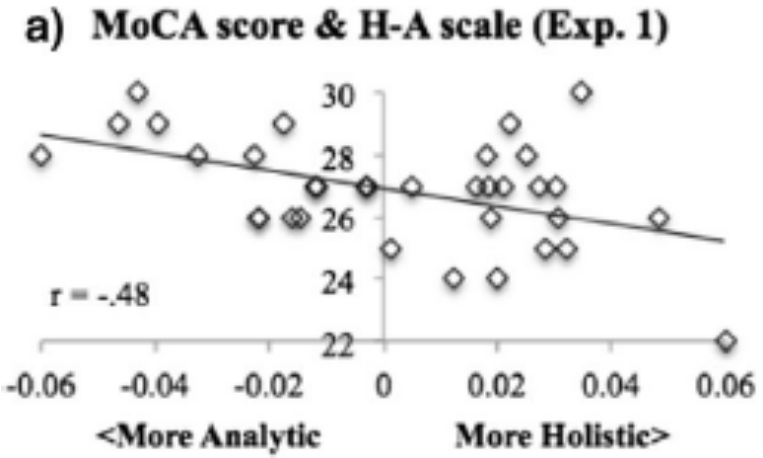
Eye movement & cognitive ability: Correlations

$$\text{H-A } Scale = \frac{Holistic\ \log\text{-}likelihood - Analytic\ \log\text{-}likelihood}{|Holistic\ \log\text{-}likelihood| + |Analytic\ \log\text{-}likelihood|}$$



- In older adults, the lower the cognitive ability (by MoCA), the higher the H-A scale:

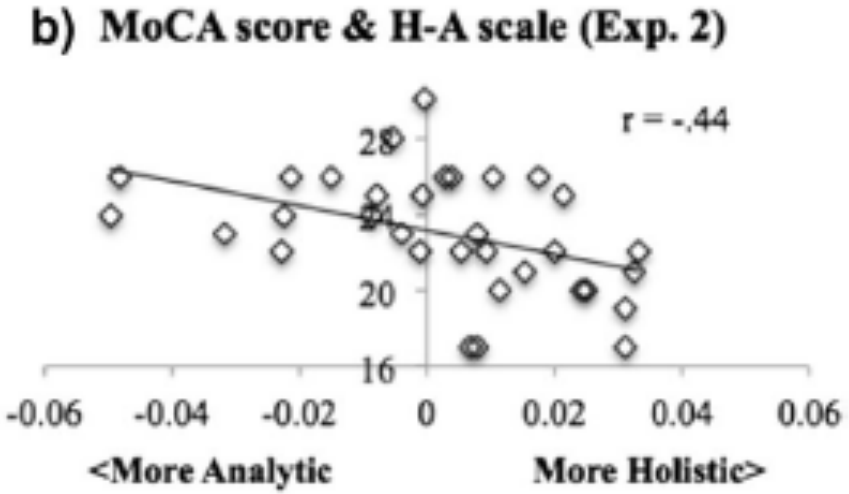
R = -.48, P = 0.004



Eye movement & cognitive ability: Correlations

- The relationship between H-A scale and cognitive ability (MoCA score) was replicated in new older adult participants (n = 38) viewing new face images using the old representative holistic and analytic HMMs.

R = -.44, p = 0.01



- This result suggests the possibility of using eye movements as an easily deployable screening assessment for cognitive decline in older adults.

Eye movement & cognitive ability: Correlations

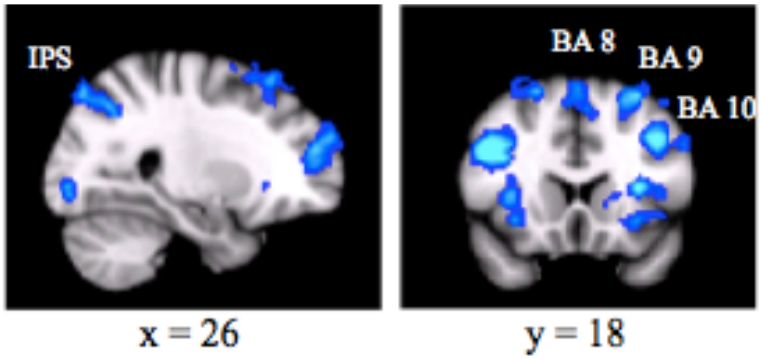
- **H-A scale was particularly correlated with executive and visual attention functions**.

	Correlation with H-A Scale	
	r	p
1. General Cognitive assessment (MoCA)	-.44	.010*
2. Executive Planning (TOL; Total moves)	.36	.043*
3. Visual Attention (TMT)	.37	.034*
4. Working Memory - Verbal 2-back	-.35	.062
- Spatial 2-back	-.35	.066
5. Verbal Memory (CAVLT)	-.17	.337
6. Verbal Fluency (CVFT)	-.15	.394

Chan, C. Y. H., Chan, A. B., Lee, T. M. C., & Hsiao, J. H. (2018). Eye movement patterns in face recognition are associated with cognitive decline in older adults. *Psychonomic Bulletin & Review, 25(6), 2200-2207.*

Eye movement & cognitive ability: Brain activation

- fMRI study with healthy young adults (Chan et al., 2016): Holistic patterns were associated with lower activation in areas important for top-down control of visual attention including the frontal eye field and intraparietal sulcus.



Chan, C. Y. H., Wong, J. J., Chan, A. B., Lee, T. M. C., & Hsiao, J. H. (2016). Analytic eye movement patterns in face recognition are associated with better performance and more top-down control of visual attention: an fMRI study. In Papafragou, A., Grodner, D., Mirman, D., & Trueswell, J.C. (Eds.), *Proceeding of the 38th Annual Con-ference of the Cognitive Science Society* (pp. 854-859). Austin, TX: Cognitive Science Society.

Summary & Discussion

- **Through EMHMM, we demonstrate for the first time in the literature an explicit link between eye movement patterns and cognitive status in older adults.**
  - This may be related to decline in visuospatial attention and executive functioning.
- **It suggests the potential use of eye tracking as an efficient and low-cost method for early detection of cognitive decline/deficits.**
  - In particular, current cognitive tests for assessment purposes are often time-consuming and cognitively demanding, and can be confounded by education level; brain imaging techniques are expensive, expertise-demanding, and not commonly available.

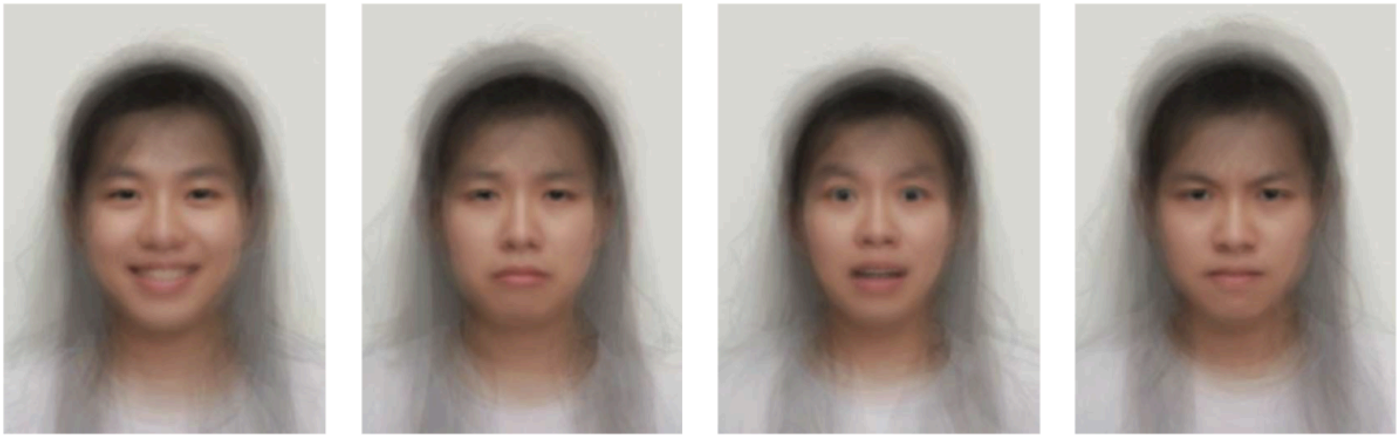
EMHMM: Example studies

- Face learning vs. face recognition
- Eye movement & cognitive ability
- Insomnia and facial expression recognition
- Eye movement & comprehension of documentaries

Insomnia and facial expression recognition

- **Individuals with insomnia have disturbed perception of facial expressions – could it be due to impaired attention control?**

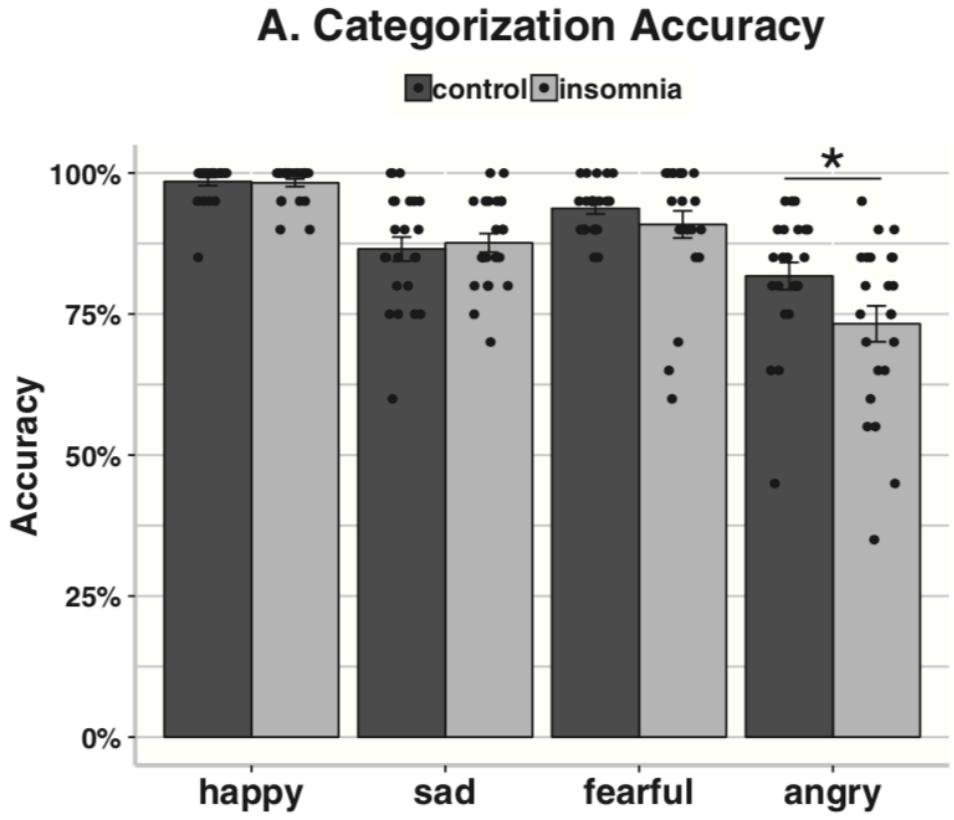
- 23 individuals with insomnia and 23 controls, performed a facial expression recognition task with happy, sad, fearful, and angry faces.

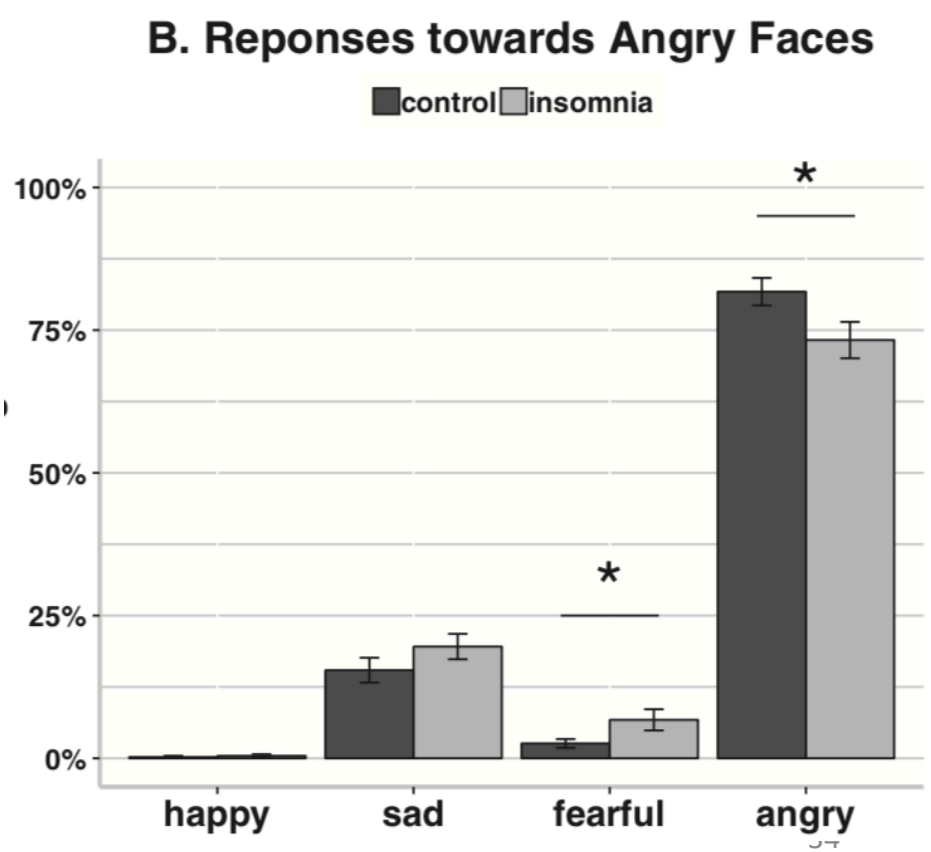


Zhang, J., Chan, A. B., Lau, E. Y. Y., & Hsiao, J. H. (2019). Individuals with insomnia misrecognize angry faces as fearful faces while missing the eyes: An eye-tracking study. *Sleep*, *42*(2), zsy220

Insomnia and facial expression recognition: Insomnia vs. control

- **Individuals with insomnia were more likely to misidentify angry faces as fearful.**





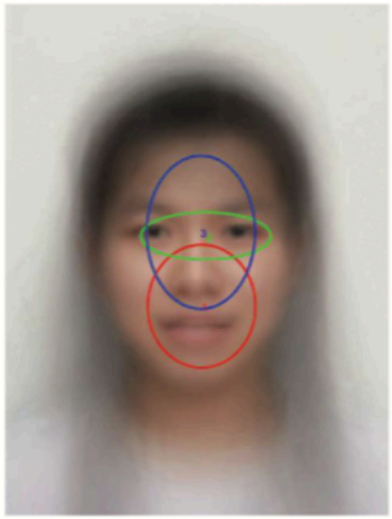
Insomnia and facial expression recognition: EMHMM Clustering

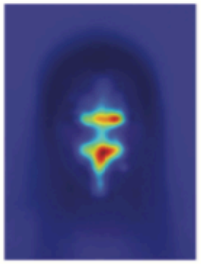
- Cluster individual HMMs into 2 groups:

Eyes-mouth patterns

A1

Overall

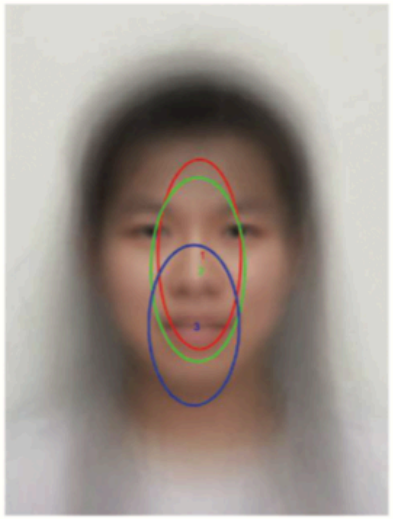


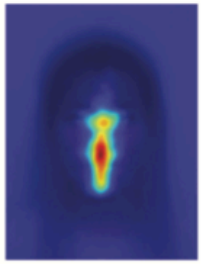


	To Red	To Green	To Blue
Priors	.54	.00	.46
From Red	.96	.04	.00
From Green	.11	.85	.04
From Blue	.01	.10	.89

Nose-mouth patterns

A2





	To Red	To Green	To Blue
Priors	.43	.15	.42
From Red	.75	.24	.01
From Green	.02	.97	.01
From Blue	.00	.01	.99

- Individuals adopting eyes–mouth patterns (accuracy: 84.5% ± .091) were more accurate to recognize angry faces than those adopting nose–mouth patterns (accuracy: 72.6% ± .150), $t(44) = 3.078$, $p = .004$

Insomnia and facial expression recognition: Insomnia vs. control

- **Most individuals with insomnia adopted the nose-mouth pattern whereas most controls adopted the eyes-mouth pattern**, X(1) = 4.39, p = .036

	Control (*n* = 23)	Insomnia (*n* = 23)	Total
Eyes–mouth patterns	13 (56.5% control)	6 (26.1% insomnia)	19
Nose–mouth patterns	10 (43.5% control)	17 (73.9% insomnia)	27

Insomnia and facial expression recognition: Summary & Conclusion

- **Individuals with insomnia may misidentify angry faces as fearful because of missing the eyes.**
  - Eye region contains the most diagnostic information for recognizing angry faces (Smith et al., 2005).

- **The compromised emotion perception in individuals with insomnia may be related to impaired visual attention control as reflected in eye movement pattern.**

Zhang, J., Chan, A. B., Lau, E. Y. Y., & Hsiao, J. H. (2019). Individuals with insomnia misrecognize angry faces as fearful faces while missing the eyes: An eye-tracking study. *Sleep*, *42*(2), zsy220

EMHMM: Example studies

- Face learning vs. face recognition
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- Insomnia and facial expression recognition
- Eye movement & comprehension of documentaries

Eye movement & comprehension of documentaries

- Does multimedia learning facilitate or impair comprehension of documentaries?
  - This may depend on individual differences in cognitive abilities and cognitive strategy as reflected in eye movement pattern.

- Here we examined whether participants' cognitive abilities and eye movement strategies for video watching would modulate the effect of subtitles and video content on the comprehension

Eye movement & comprehension of documentaries

Participants

- 60 native Mandarin speakers, 18-30 years old

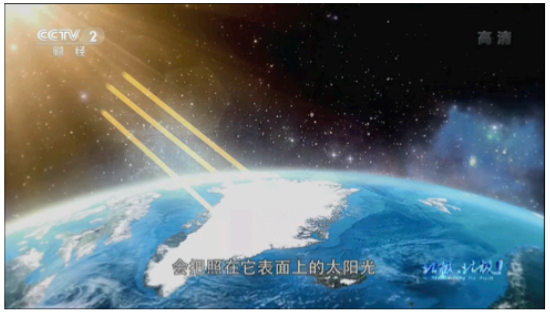
Materials

- 16 clips in ecology, astronomy, geography & chemistry (4 in each topic)
- The length: 75 s
- 4 different conditions

Audio baseline condition

Video-only condition

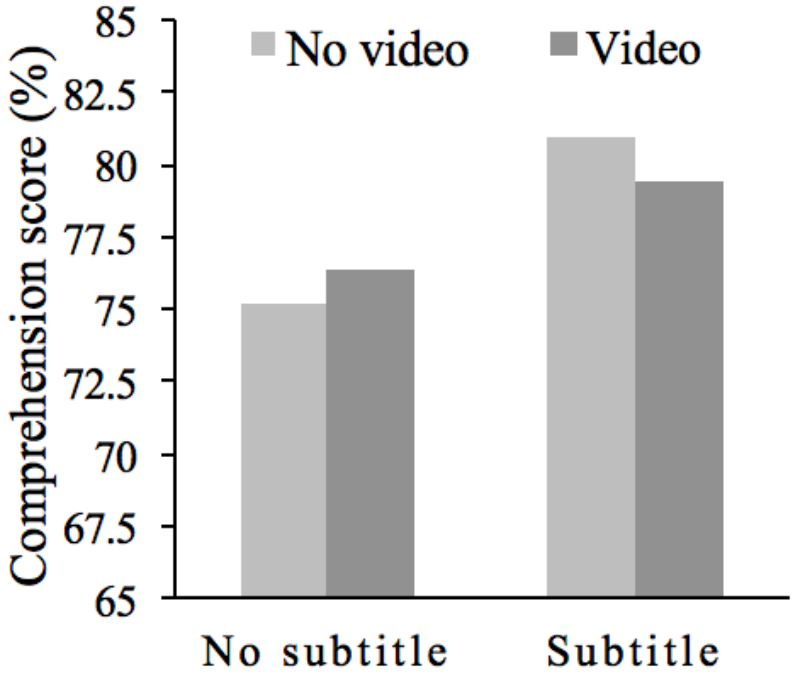
Subtitles-only condition



Video with subtitles condition

Behavioral results

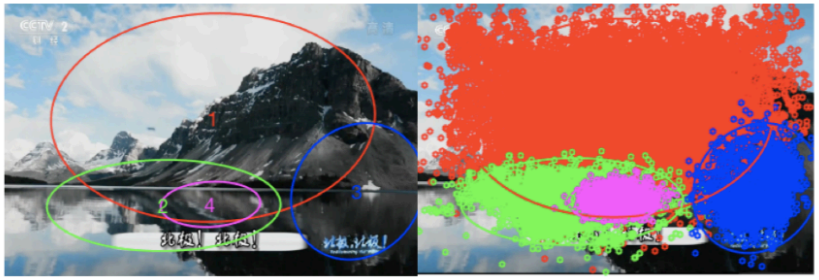
- A significant main effect of subtitle
- No main effect of video content or interaction between video content and subtitle.



✓ **Subtitles facilitated comprehension of documentaries.**

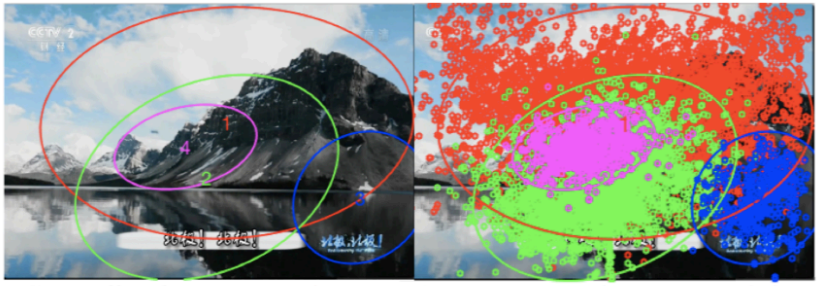
Eye movement pattern in video-only condition

Distributed Strategy



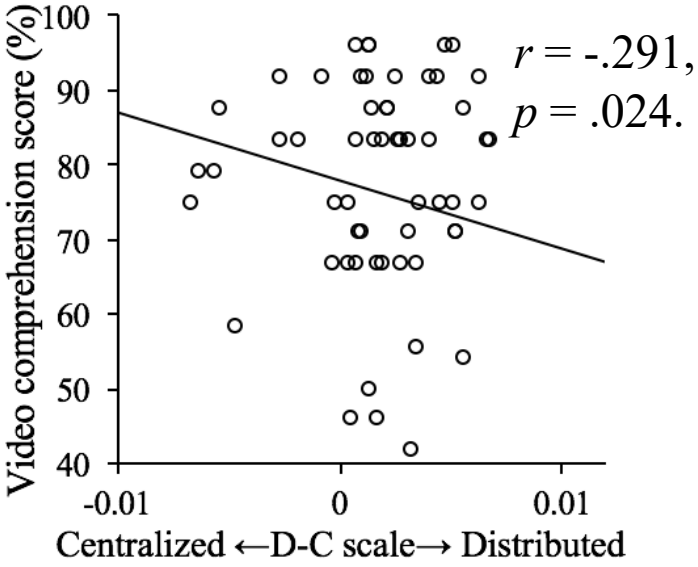
Distributed	To Red	To Green	To Blue	To Pink
Priors	1.0	.00	.00	.00
From Red	.92	.05	.02	.01
From Green	.37	.56	.07	.00
From Blue	.38	.12	.47	.04
From Pink	.27	.00	.08	.64

Centralized Strategy

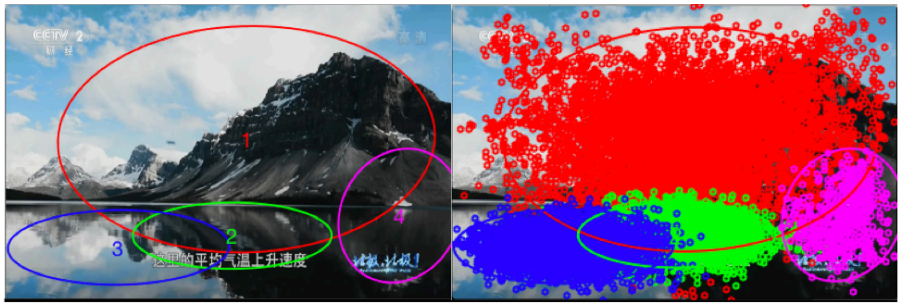


Centralized	To Red	To Green	To Blue	To Pink
Priors	.46	.44	.01	.00
From Red	.91	.08	.01	.00
From Green	.18	.78	.04	.01
From Blue	.17	.39	.44	.00
From Pink	.03	.04	.00	.93

- The more distributed the pattern the lower the comprehension score.
- Participants' comprehension could be predicted by a linear combination of auditory working memory, task switching ability, and eye movement pattern.

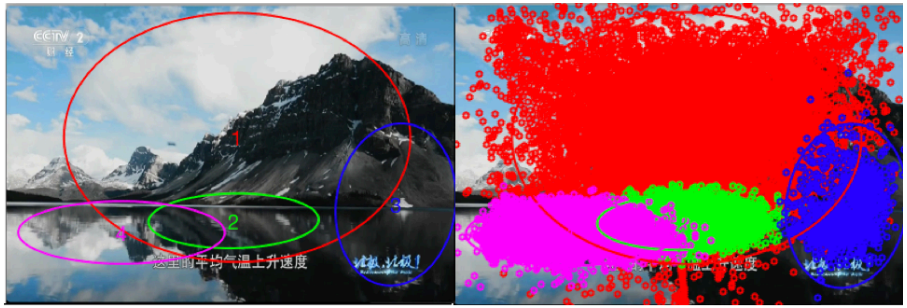


Eye movement pattern in video with subtitles condition



Group1	To Red	To Green	To Blue	To Pink
Priors	0.98	.00	.02	.00
From Red	.74	.14	.11	.02
From Green	.22	.76	.01	.01
From Blue	.24	.01	.74	.01
From Pink	.23	.13	.13	.51

Group 1: focus more on the subtitles



Group2	To Red	To Green	To Blue	To Pink
Priors	.99	.00	.00	.01
From Red	.79	.10	.01	.09
From Green	.22	.76	.01	.00
From Blue	.22	.13	.53	.11
From Pink	.24	.00	.01	.75

Group 2

- None of the cognitive ability and eye movement pattern measures could predict comprehension outcome.

Eye movement & comprehension of documentaries: Conclusion

- Adding subtitles is beneficial to comprehension of documentaries regardless of eye movement strategy or cognitive abilities.
- Effect of video content depends on cognitive abilities and eye movement strategies.
  - For viewing video clips without subtitles, people with higher auditory working memory capacity, higher task switching ability, and more centralized eye movement pattern show better comprehension outcome.

Zheng, Y., Ye, X., & Hsiao, J. H. (2019). Does Video Content Facilitate or Impair Comprehension of Documentaries? The Effect of Cognitive Abilities and Eye Movement Strategy. *Proceeding of the 41th Annual Conference of the Cognitive Science Society.* **[Student Travel Award Winner]**

Outline

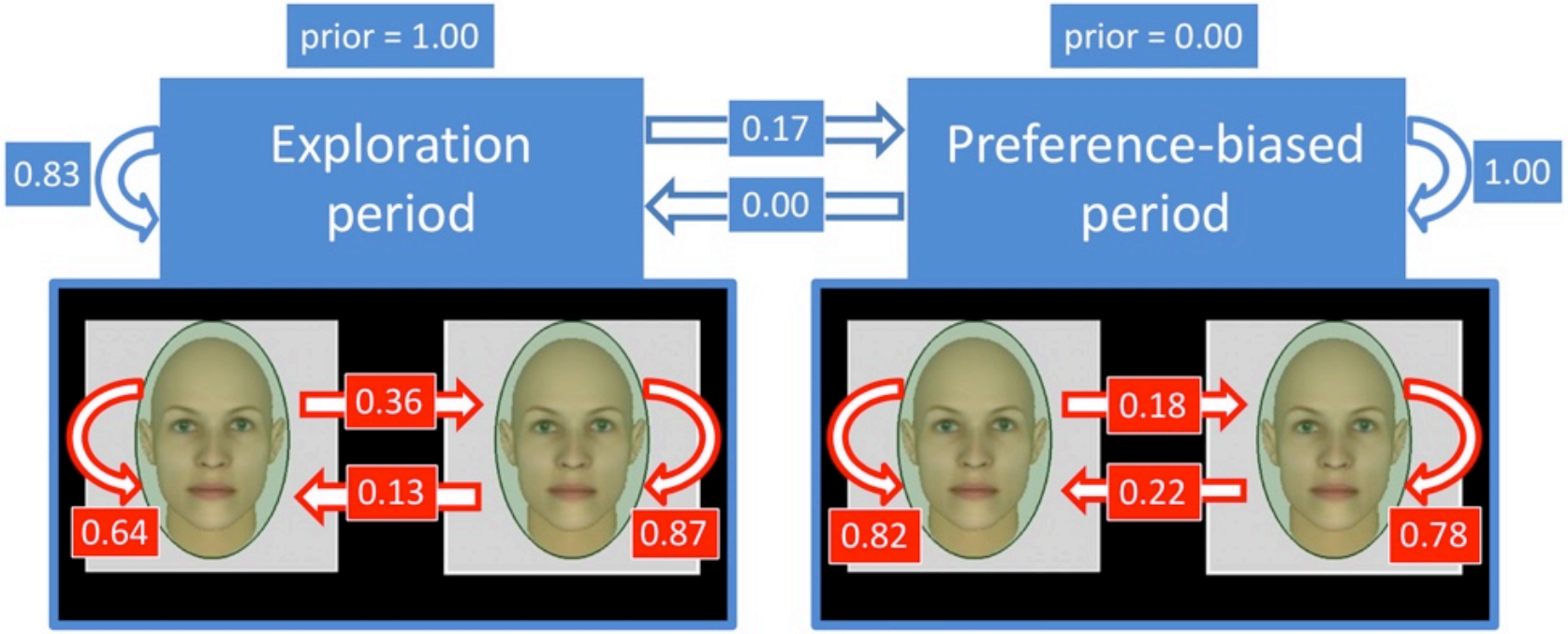
- **Introduction to EMHMM**
  - EMHMM: Example studies
  - EMHMM with co-clustering
  - EMSHMM (Switching HMM)
- **Forming project groups**
- **EMHMM toolbox tutorial**

EMHMM with co-clustering

- **How to summarize a general eye movement strategy in tasks where stimuli's feature layouts differ significantly** (e.g., scene perception, visual search, reading etc.)?
- **EMHMM with co-clustering**: 1 stimulus 1 model; use co-clustering to discover participants using the same pattern across stimuli.

EMSHMM (Switching HMM)

- **For analyzing eye movements in cognitive tasks involving cognitive state changes** (e.g., decision making).
- A switching hidden Markov model (SHMM) to capture a participant's cognitive state transitions, with eye movement patterns during each cognitive state being summarized using a regular HMM.



Introduction to EMHMM and Its Applications : Summary

- EMHMM allows us to :
  - Summarize a person's eye movements in terms of personalized ROIs and transition probabilities using an HMM.
  - Discover common eye movement patterns among participants.
  - Quantitatively assess eye movement pattern similarity.
  - Discover associations between eye movements and other measures (e.g., performance, brain imaging data, etc.).

- **Eye Movement analysis with HMMs (EMHMM) Toolbox is available: http://visal.cs.cityu.edu.hk/research/emhmm/**

- **EMHMM with co-clustering & EMSHMM will be available on the same website soon.**

Outline

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