Deep Learning-based VR Sickness Assessment

IEEE SA WG3079 Meeting
: HMD based 3D Content Motion Sickness Reducing Technology

Hak Gu Kim
hgkim0331@kaist.ac.kr

Image and Video Systems Lab.
School of Electrical Engineering
Korea Advanced Institute of Science and Technology (KAIST)

July. 2018

Virtual Reality (VR)



VR displays

360 cameras



Training

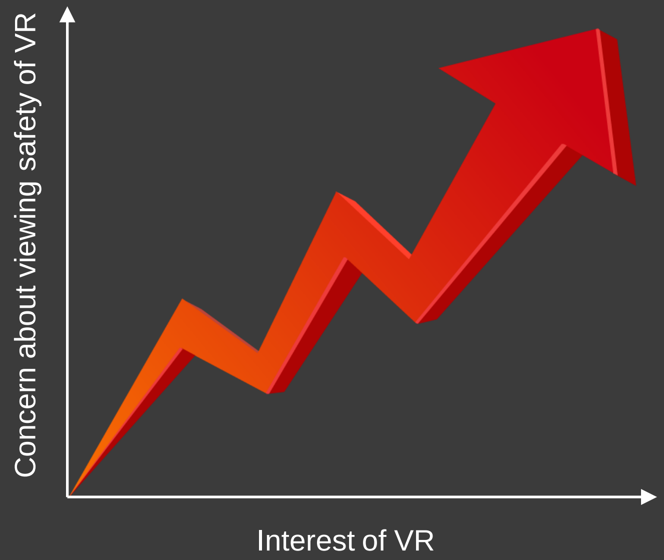
Entertainment

Education

Healthcare

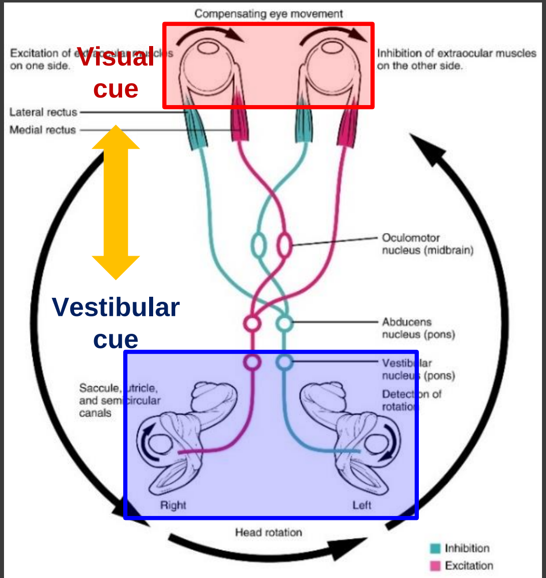
Immersive 360-degree VR Content

VR Sickness (≈Cybersickness)

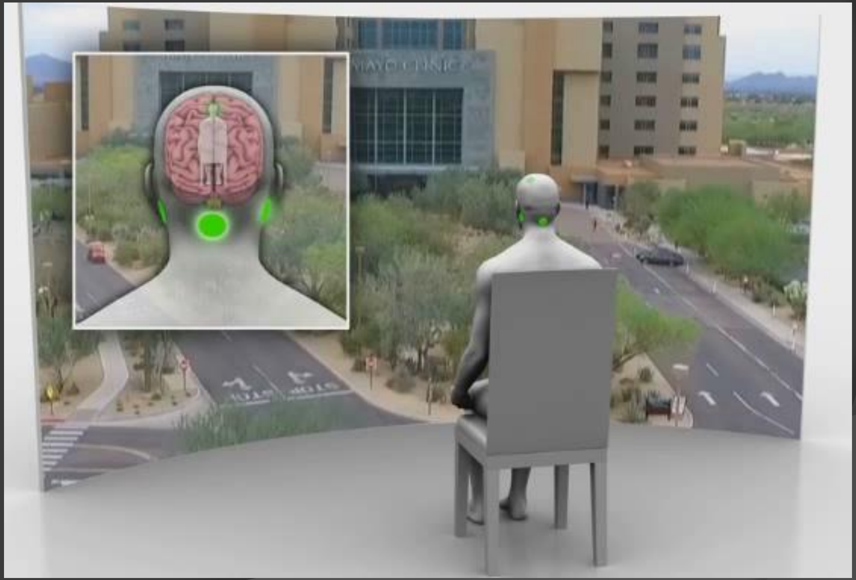


Main Factors of VR Sickness

- **Visual-Vestibular Conflict**
  - Mismatches between simulation motion of VR content and viewer's motion



Visual-vestibular interaction[1]



Visual-vestibular conflict in VR experience[2]

[1] http://oerpub.github.io/epubjs-demo-book/content/m46557.xhtml
[2] Mayo Clinic Research

VR Sickness Assessment (VRSA)

Objective assessment

Subjective assessment

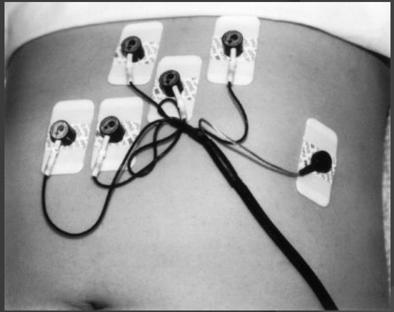
Objective VRSA: Physiological Measurements

Physiological measurements

EEG

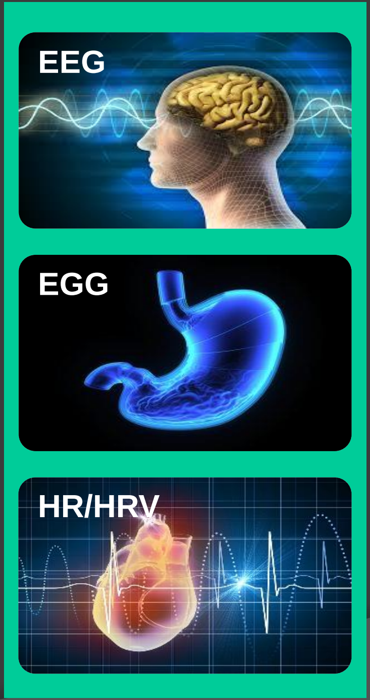
Objective VRSA: Physiological Measurements

Physiological measurements



Objective VRSA: Physiological Measurements

Physiological measurements

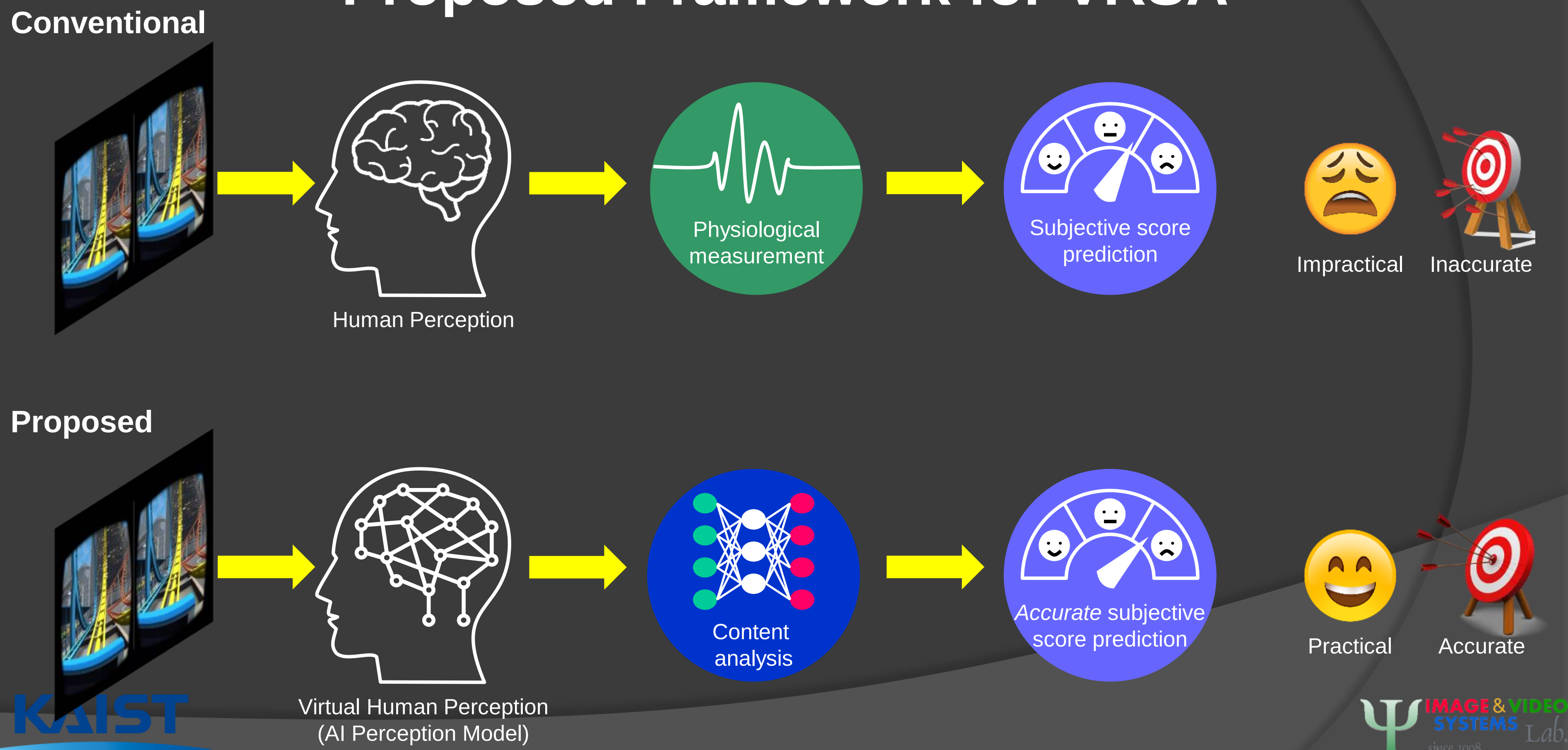


Subjective VRSA: Subjective Questionnaires

Physiological measurements

Subjective questionnaires

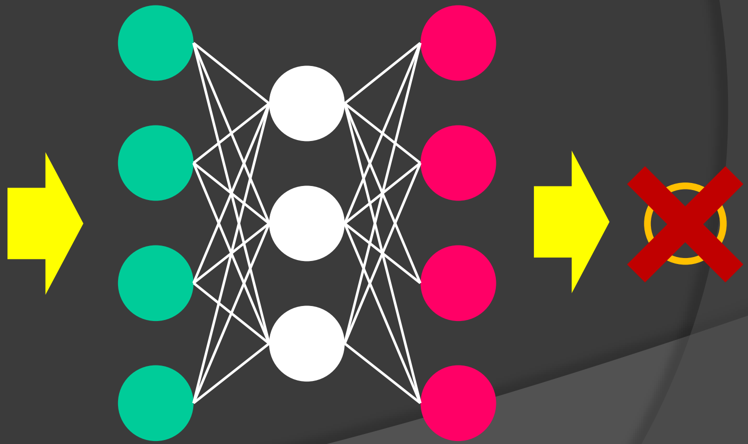
Proposed Framework for VRSA



Challenges

- **Lack of labeled datasets**
  - It is difficult to collect a large-scale of fully labeled datasets
    - VR content and the corresponding subjective scores

A large number of target images

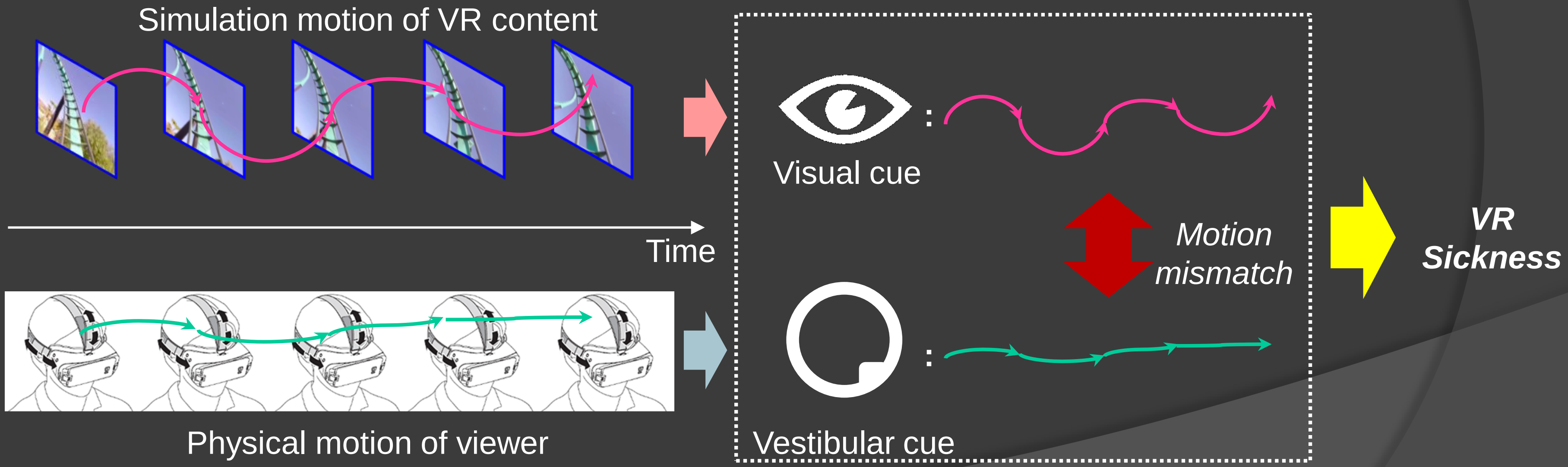


Regression

Corresponding subjective score

Proposed Method (1/5)

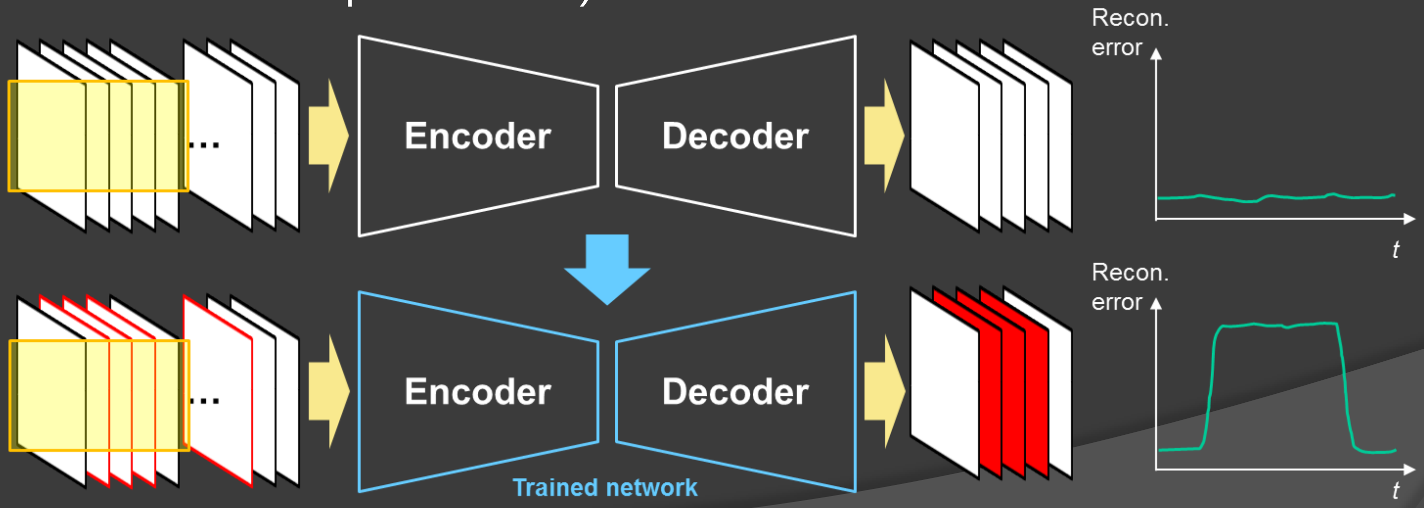
- **Visual-vestibular conflict**
  - Caused by exceptional motion of VR content



Proposed Method (2/5)

Main Idea of Our Research

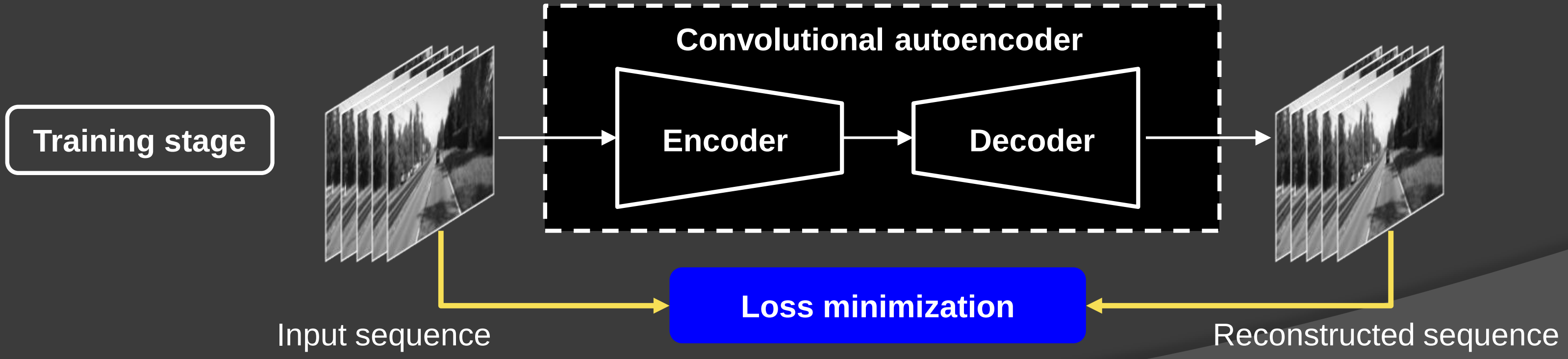
- Deep learning based generative model
- Non-excessive VR sickness feature representation (instead of excessive VR sickness feature representation)



Proposed Method (3/5)

Overall Procedure of the Proposed VRSA Framework

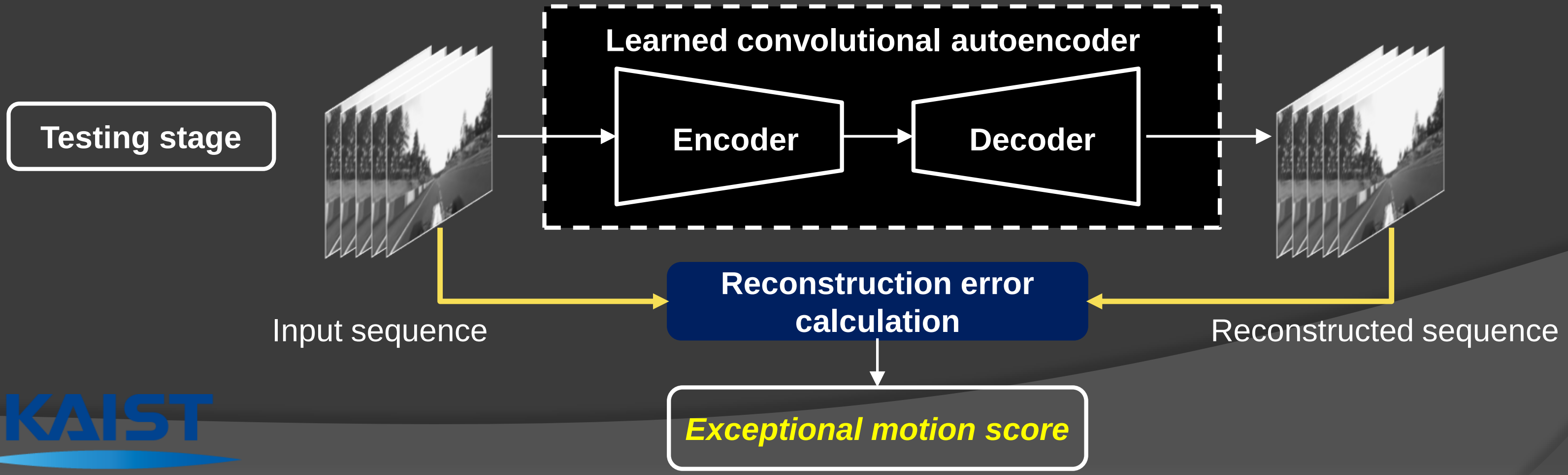
- In training, the convolutional autoencoder is trained to reconstruct original VR video sequences with non-exceptional motion such as slow and moderate motion velocity.
- In testing, by measuring the reconstruction error of the motion information in VR video content, the exceptional motion of VR video content can be detected and measured.



Proposed Method (3/5)

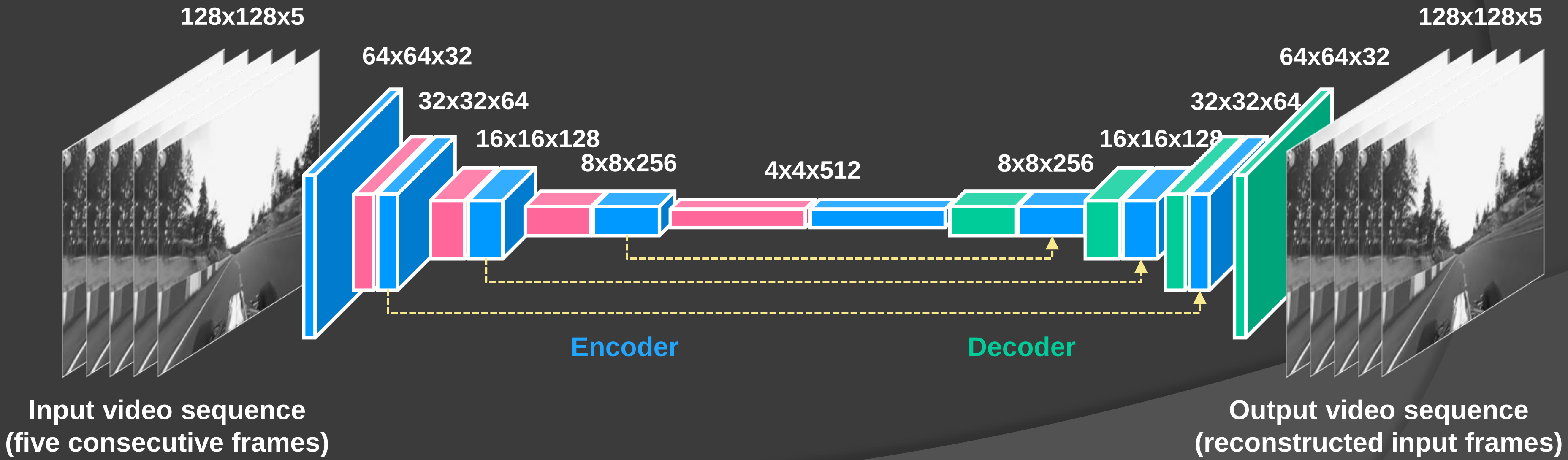
Overall Procedure of the Proposed VRSA Framework

- In training, the convolutional autoencoder is trained to reconstruct original VR video sequences *with non-exceptional motion* such as slow and moderate motion velocity.
- In testing, by measuring the reconstruction error of the motion information in VR video content, the exceptional motion of VR video content can be detected and measured.



Proposed Method (4/5)

- **Deep Convolutional Autoencoder for Normal Motion Patterns Learning**
  - Encoder for representing the latent spatio-temporal feature of input sequence
  - Decoder for reconstructing the original sequence from the encoded features

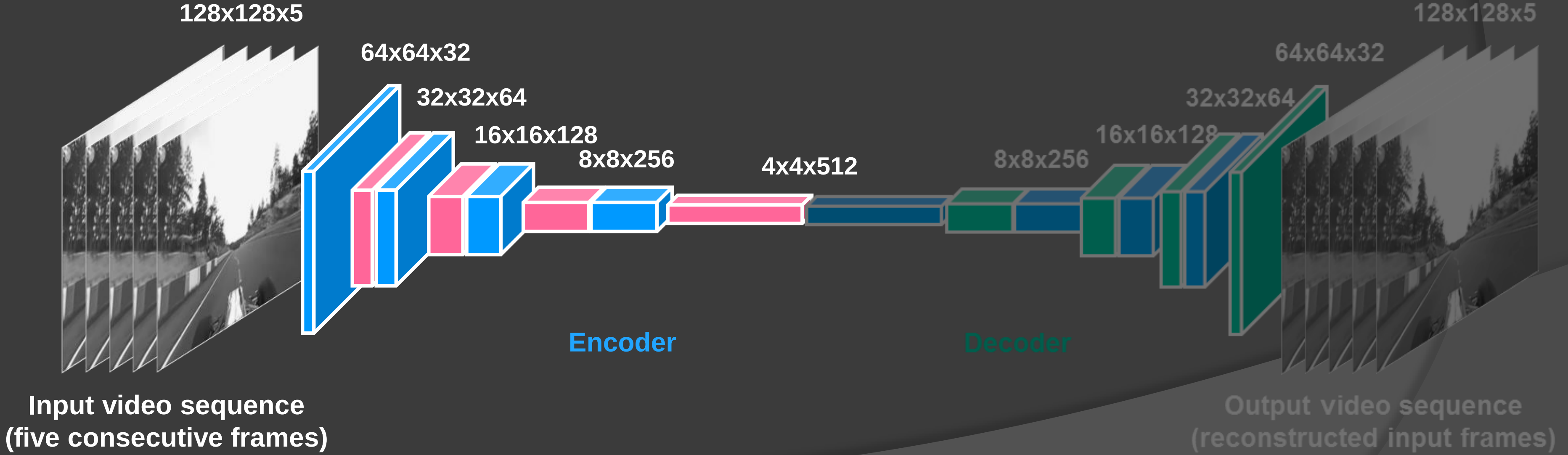


KAIST

IMAGE & VIDEO SYSTEMS Lab. since 1998

Proposed Method (4/5)

- **Deep Convolutional Autoencoder for Normal Motion Patterns Learning**
  - Encoder for representing the latent spatio-temporal feature of input sequence
  - Decoder for reconstructing the original sequence from the encoded features

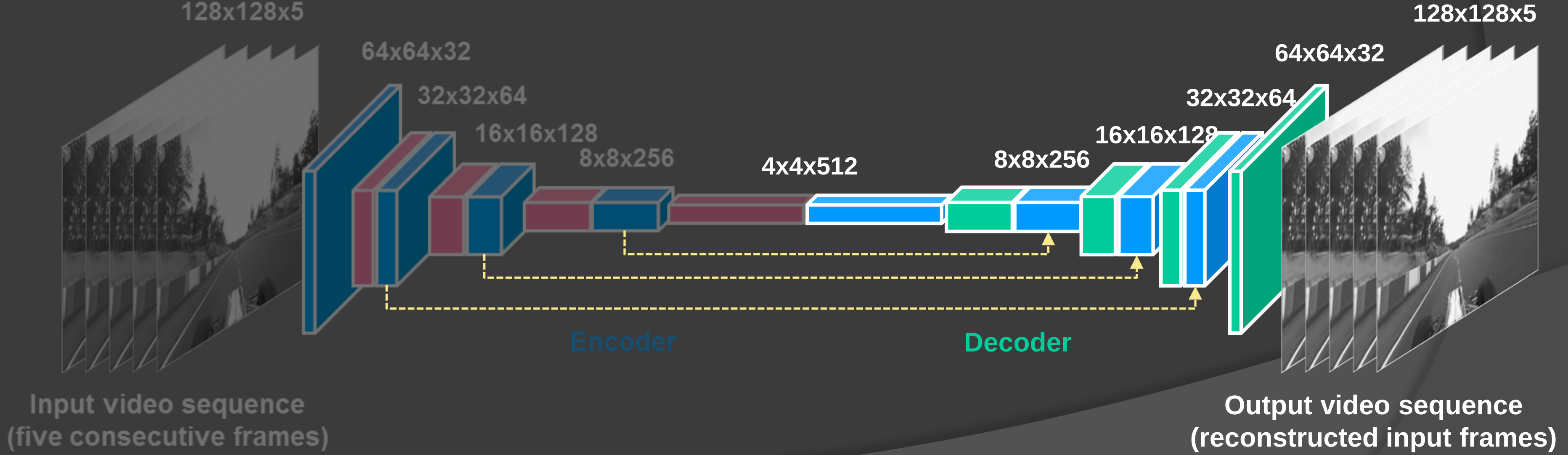


KAIST

IMAGE & VIDEO SYSTEMS Lab. since 1998

Proposed Method (4/5)

- **Deep Convolutional Autoencoder for Normal Motion Patterns Learning**
  - Encoder for representing the latent spatio-temporal feature of input sequence
  - Decoder for reconstructing the original sequence from the encoded features



Proposed Method (5/5)

Exceptional Motion Pattern Score

- Reconstruction error at *t*-th frame of test dataset

$$e(t) = \sum_{i=1}^{W} \sum_{j=1}^{H} \left\| \boldsymbol{I}(i,j,t) - \hat{f}_W\big(\boldsymbol{I}(i,j,t)\big) \right\|^2$$

$\boldsymbol{I}(i,j,t)$: Original *t*-th frame
$\hat{f}_W\big(\boldsymbol{I}(i,j,t)\big)$: Reconstructed *t*-th frame
W and H: width and height of the frame

- Proposed exceptional motion pattern score

$$s_m(t) = \frac{e(t)}{\sqrt{W \times H}}$$

$e(t)$: Reconstruction error at *t*-th frame
W and H: width and height of the frame

Experiments and Results (1/7)

- **Datasets for Training**
  - UCSD Ped 1 and Ped 2
    - Ped 1: 34 training video clips (200 frames)
    - Ped 2: 16 training video clips (120~180 frames)
  - Avenue
    - 16 training video clips (180~360 frames)
  - KITTI benchmark
    - 61 video clips

UCSD Ped1

UCSD Ped12

Avenue

KITTI Benchmark

KAIST

DEO SYSTEMS Lab. since 1998

Experiments and Results (2/7)

Datasets for Test

- Three 360-degree VR video contents, collected from Youtube[3],[4],[5]
  - Video 1: Slow velocity
  - Video 2: Moderate velocity
  - Video 3: Fast velocity

Video 1

Video 2

Video 3

[3] https://www.youtube.com/watch?v=JEr3-FzSgzk
[4] https://www.youtube.com/watch?v=wECZs7hewjY
[5] https://www.youtube.com/watch?v=wfNvZwN87Hg

Experiments and Results (3/7)

- **Subjective Assessment Experiment**
  - Equipment for displaying VR content
    - Oculus Rift CV1 HMD
      - 2160 x 1200 pixels @ 90 Hz
      - FoV: 110 degree
    - Intel Core i7-4770@3.4 GHz, 32GB RAM, and NVIDIA GTX 1080TI

- Subjects
  - 15 subjects, ranging between 20 to 30 years old
    - Normal or corrected-to-normal vision
    - Minimum stereopsis: 60 arcsec.

KAIST

IMAGE & VIDEO SYSTEMS Lab. since 1998

Experiments and Results (4/7)

Subjective Assessment Experiment

- 16-item SSQ[6]

SIMULATOR SICKNESS QUESTIONNAIRE
Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

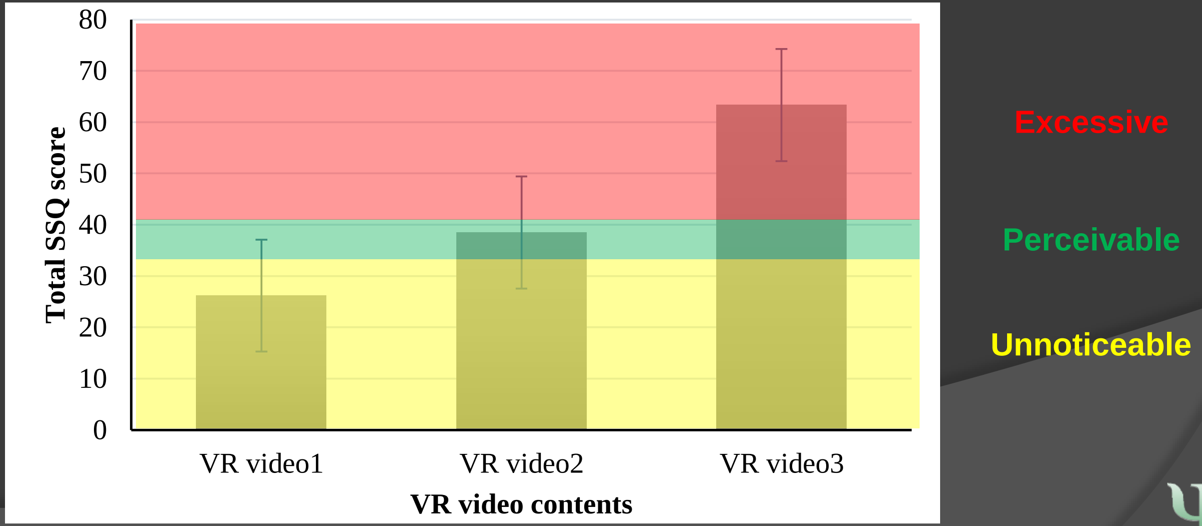
- Procedure
  - A week before the actual subjective assessment experiments, we had subjects experience a variety of VR contents with Oculus Rift in order to allow them familiarize with VR environment.
  - Every VR video content was displayed for 2 minutes through Oculus Rift CV1.
  - After watching the VR video contents, subjects rated their perception of the VR sickness for each symptom in SSQ sheet .

[6] Kennedy et al. Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 1993

Experiments and Results (5/7)

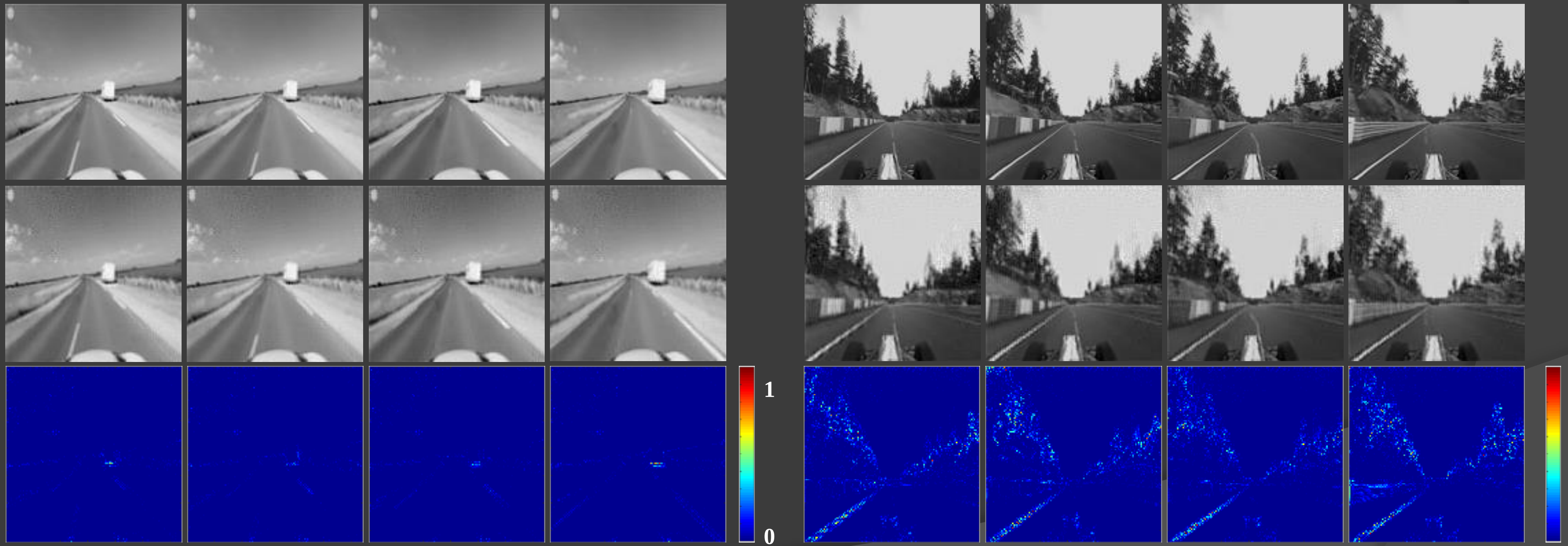
Subjective Assessment Results

- Degree of VR sickness subjects felt was proportional to the motion magnitude.
- The subjective results show that subjects felt some symptoms of VR sickness when watching VR video 2 and 3. In particular, VR video 3 could lead to excessive VR sickness



Experiments and Results (6/7)

- **Performance of the Proposed Network**



Reconstruction results of the proposed deep convolutional autoencoder network
for VR video 1 with slow motion (left) and VR video 3 with exceptional motion (right)

KAIST

IMAGE & VIDEO SYSTEMS Lab. since 1998

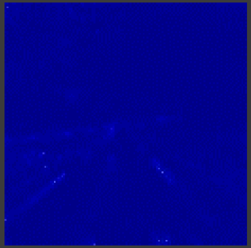
Experiments and Results (7/7)

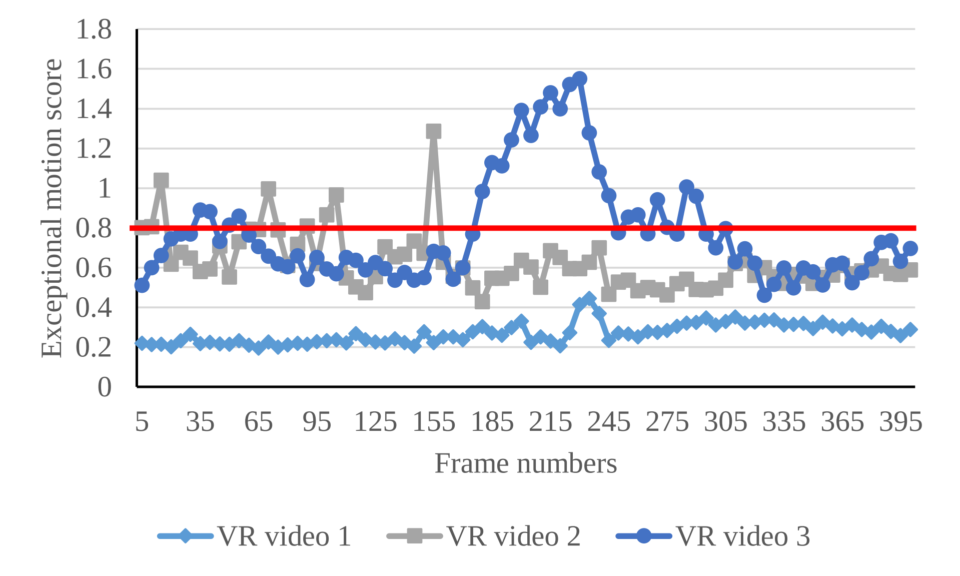
Performance of the Proposed Network

360 degree video with slow motion pattern


Original seq.


Reconstructed seq.

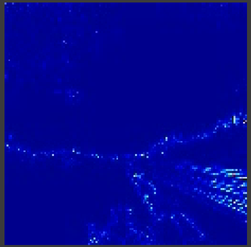

Recon. error



360 degree video with fast motion pattern


Original seq.


Reconstructed seq.


Recon. error

Conclusions

- This paper presented a novel measurement of exceptional motion using deep convolutional autoencoder network for assessing the VR sickness of VR video content.
- The convolutional autoencoder learned by normal datasets with slow and moderate motion could reconstruct the non-exceptional motion patterns but it could not recover VR video content having exceptional motion.
- Based on the fact that exceptional motion led to high reconstruction errors in the deep autoencoder network, the level of VR sickness of the input VR video content due to exceptional motion could be predicted.
- The results of our subjective assessment experiments showed that the proposed objective measure strongly had a high correlation with human subjective quality scores, SSQ of our test datasets (PLCC was 0.92).

Thank you

http://ivylab.kaist.ac.kr
hgkim0331@kaist.ac.kr

Appendix

- **Total SSQ score**
  - 1. Nausea score
  - 2. Oculomotor score
  - 3. Disorientation score
  - Total SSQ = 3.74 x (1 + 2+ 3)

Table 1: SSQ used in our subjective assessment

SSQ Symptoms	Nausea	Oculomotor	Dis-orientation
General discomfort	O	O	
Fatigue		O	
Headache		O	
Eye strain		O	
Difficulty focusing		O	
Increased salivation	O		O
Sweating	O		
Nausea	O		
Difficulty concentrating	O	O	O
Fullness of head			
Blurred vision		O	O
Dizzy (Eyes open)			O
Dizzy (Eye closed)			O
Vertigo			O
Stomach awareness	O		O
Burping	O		