A QoE and Simulator Sickness Evaluation of a Smart-Exercise-Bike Virtual Reality System via User Feedback and Physiological Signals

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Motivation

• Exergaming is highly beneficial due to motivating people to engage into physical exercise

• Cycling exergames have received a lot of attention:
  • Low cost
  • Availability of equipment
  • Familiarity with activity

• Use of virtual reality in cycling exergames:
  • More immersive experience
  • Increased motivation to exercise

• Study on visual quality perception and simulator sickness required
Developed system overview
Bike Hardware & Software

Bike module

- Designed as plug and play kit
- Micro-controller based custom circuit
- Magnetic switch for pedalling detection
- Buttons on handlebar for steering
- USB connection for power supply and signal transmission

Bike server

- Receives signals from bike module
- Steering button presses converted to OS key presses
  - Continuous pressing supported
- Rotation signal handling:
  - As OS key press, or
  - Transmission of rotation speed in RPM via TCP/IP socket
- Key mapping supported
The VR environment
Experiment overview

• Users asked to use the VR system for various visual quality settings
  • Texture resolution
  • Frame rate

• Physiological signals captured while using the system
  • Electrocardiography (ECG)
  • Galvanic Skin Response (GSR)

• Self-assessment of visual quality and simulator sickness symptoms
  • MOS ratings
  • Simulator Sickness Questionnaire (SSQ)

• Study of the effects of
  • Quality settings on perceptual quality
  • Quality settings on simulator sickness scores
  • Physiological responses on perceptual quality
  • Physiological responses on simulator sickness scores
Head-mounted display

**Oculus Rift**

- OLED panels
- 1080 x 1200 pixels per eye panel
- 90 Hz refresh rate
- 2160 x 2400 total resolution
- 110° field of view
- Headphones
Self-assessment scales

MOS scale

<table>
<thead>
<tr>
<th>Value</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bad</td>
</tr>
<tr>
<td>2</td>
<td>Poor</td>
</tr>
<tr>
<td>3</td>
<td>Fair</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Simulator sickness questionnaire

**Symptoms:**
1) general discomfort, 2) fatigue, 3) headache, 4) eye strain, 5) difficulty focusing, 6) increased salivation, 7) sweating, 8) nausea, 9) difficulty concentrating, 10) fullness of head, 11) blurred vision, 12) dizziness (eyes open), 13) dizziness (eyes closed), 14) vertigo, 15) stomach awareness, 16) burping

**4-point scale:**
0: None, 1: Slight, 2: Moderate, 3: Severe
Experimental protocol

- Written instructions for the experiment
- Clarifications from supervising researcher
- Consent form and prior experience questionnaire
- Attachment of ECG and GSR electrodes and positioning and adjustment of HMD
- 3 random test scenarios performed for familiarisation
  - 30 sec at the highest quality setting
  - 60 sec at the test quality setting
  - Quality assessment & Simulator sickness questionnaire
- All test scenarios performed twice in random order
  - 30 sec at the highest quality setting
  - 60 sec at the test quality setting
  - Quality assessment & Simulator sickness questionnaire
# Quality settings

<table>
<thead>
<tr>
<th>#</th>
<th>Texture quality setting</th>
<th>Frame rate setting</th>
<th>Texture resolution (Width x Height)</th>
<th>Frame rate (fps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>High</td>
<td>High</td>
<td>1024 x 1024</td>
<td>60</td>
</tr>
<tr>
<td>MH</td>
<td>Medium</td>
<td>High</td>
<td>512 x 512</td>
<td>60</td>
</tr>
<tr>
<td>LH</td>
<td>Low</td>
<td>High</td>
<td>256 x 256</td>
<td>60</td>
</tr>
<tr>
<td>RH</td>
<td>Random low quality textures</td>
<td>High</td>
<td>Random textures at 256 x 256</td>
<td>60</td>
</tr>
<tr>
<td>HM</td>
<td>High</td>
<td>Medium</td>
<td>1024 x 1024</td>
<td>30</td>
</tr>
<tr>
<td>HL</td>
<td>High</td>
<td>Low</td>
<td>1024 x 1024</td>
<td>15</td>
</tr>
</tbody>
</table>
VR questionnaire

Rate Current Quality
Bad Poor Fair Good Excellent

General Discomfort
None Slight Moderate Severe

Fatigue
None Slight Moderate Severe

Headache
None Slight Moderate Severe
### Participants

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of participants</td>
<td>18 (16 male, 2 female)</td>
</tr>
</tbody>
</table>
| Age                      | $\mu = 26$  
                          | $\sigma = 5.65$ |
| Occupation               | Undergraduate students  
                          | Postgraduate students  
                          | PhD students           |
| Eyesight                 | Normal / Corrected |

**Prior VR experience**

- None: 6
- Regular use: 9
- Up to 10 times: 2
- 1-3 Times: 1
Quality assessment

![Bar chart showing quality assessment results for different settings]

- HH: Mean Opinion Score
- MH: Mean Opinion Score
- LH: Mean Opinion Score
- HM: Mean Opinion Score
- HL: Mean Opinion Score
- RH: Mean Opinion Score
Simulator sickness scores

![Graph showing simulator sickness scores](image-url)
Max/Avg simulator sickness total scores

![Bar chart showing max and average total scores for participants](chart.png)
Factors affecting quality perception and simulator sickness

### Quality perception

<table>
<thead>
<tr>
<th>Factor</th>
<th>ANOVA $p$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture resolution</td>
<td>0.0012</td>
<td>YES</td>
</tr>
<tr>
<td>Frame rate</td>
<td>0.0127</td>
<td>YES</td>
</tr>
<tr>
<td>Quality setting</td>
<td>0.0010</td>
<td>YES</td>
</tr>
</tbody>
</table>

### Simulator sickness scores

<table>
<thead>
<tr>
<th>Factor</th>
<th>ANOVA $p$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture resolution</td>
<td>0.8463</td>
<td>NO</td>
</tr>
<tr>
<td>Frame rate</td>
<td>0.6759</td>
<td>NO</td>
</tr>
<tr>
<td>Quality setting</td>
<td>0.9287</td>
<td>NO</td>
</tr>
<tr>
<td>VR experience</td>
<td>$1.6 \times 10^{-11}$</td>
<td>YES</td>
</tr>
<tr>
<td>Gender*</td>
<td>0.0169</td>
<td>YES</td>
</tr>
</tbody>
</table>

*Results for gender are biased due to sample size
Simulator sickness scores vs VR experience

![Graph showing simulator sickness scores vs VR experience]

- Nausea
- Oculomotor
- Disorientation
- Total Score

VR experience categories:
- None
- 1-3 Times
- Up to 10 times or Regular use
Effect of physiological signals on perceptual quality and simulator sickness scores

### Quality perception

<table>
<thead>
<tr>
<th>Factor</th>
<th>ANOVA $p$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSR peaks</td>
<td>0.2756</td>
<td>NO</td>
</tr>
<tr>
<td>Mean HR</td>
<td>0.9387</td>
<td>NO</td>
</tr>
<tr>
<td>Min HR</td>
<td>0.9649</td>
<td>NO</td>
</tr>
<tr>
<td>Max HR</td>
<td>0.8314</td>
<td>NO</td>
</tr>
<tr>
<td>Median HR</td>
<td>0.9273</td>
<td>NO</td>
</tr>
<tr>
<td>St.Dev. HR</td>
<td>0.8124</td>
<td>NO</td>
</tr>
</tbody>
</table>

### Simulator sickness scores

<table>
<thead>
<tr>
<th>Factor / PCC</th>
<th>TS</th>
<th>N</th>
<th>O</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSR peaks</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>-0.05</td>
</tr>
<tr>
<td>Mean HR</td>
<td>-0.12</td>
<td>-0.17</td>
<td>-0.04</td>
<td>-0.15</td>
</tr>
<tr>
<td>Min HR</td>
<td>-0.09</td>
<td>-0.13</td>
<td>-0.00</td>
<td>-0.13</td>
</tr>
<tr>
<td>Max HR</td>
<td>-0.09</td>
<td>-0.13</td>
<td>-0.03</td>
<td>-0.12</td>
</tr>
<tr>
<td>Median HR</td>
<td>-0.13</td>
<td>-0.17</td>
<td>-0.04</td>
<td>-0.16</td>
</tr>
<tr>
<td>St.Dev. HR</td>
<td>0.06</td>
<td>0.07</td>
<td>0.01</td>
<td>0.09</td>
</tr>
</tbody>
</table>

PCC: Pearson’s Correlation Coefficient
Conclusions

• Texture resolution, frame rate, and their combination:
  • Had a statistically significant impact on the perceived visual quality
  • Did not have a statistically significant impact on simulator sickness scores
  • Did not have a statistically significant impact on physiological responses

• Moving speed and focus on not crashing the virtual bike prevented users from noticing quality degradation:
  • Between 60 and 30 fps
  • When random low resolution textures were used

• Weak correlation between physiological responses and simulator sickness scores
  • Strenuous activity (pedalling) led to increased sweating and cardiac activity, interfering with the physiological responses related to simulator sickness

• Prior experience with VR had a statistically significant impact on simulator sickness scores
  • Slow familiarisation period with the system recommended
Thank you