



Virtual Reality Sickness and Challenges Behind Different Technology and Content Settings

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Abstract

VR sickness (Cybersickness) presents an important challenge in virtual reality environments. We present the results of a study on the effects of VR technology and VR video content type on VR sickness and on autonomous nervous system of the user. The participants watched two omnidirectional (360°) videos of different content types (neutral and action) on five distinct video display types (2D TV screen, three generations of Oculus Rift VR HMDs and on the mobile Samsung GearVR HMD). The Simulator Sickness Questionnaire (SSQ) in combination with the measurement of the physiological parameters (skin conductance and skin temperature, respiratory frequency and heart rate) were used to monitor the participants' physiology. The results show that video content significantly affects the SSQ grading and the skin conductance level. VR sickness effects were significantly reported less often with TV display type than with other VR HMDs.

Keywords Virtual reality · VR sickness · SSQ · Cybersickness · Psychophysiology · Skin conductance

1 Introduction

Virtual reality technologies (VR) have recently gained a lot of research attention as well as popularity across industries due to its ability to engage users on a level unprecedented by other media and technologies. VR has many definitions, and according to [1] the virtual reality experience can be described as “*The illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on three-dimensional (3D), stereoscopic, head-tracked displays, hand/body tracking and binaural sound. VR is an immersive, multi-sensory experience.*” The inherent ability to put the user in a completely new simulated environment, providing a high level of realism, immersion and interaction,

enables the users a more personal and deeper experience, which led to a widespread use of the VR solutions in entertainment, business, education and healthcare segments as well as research areas in [2]. VR solutions are especially effective in education applications where the VR immersion can provide students with a deeper understanding of course content and spark new solutions and ideas [3]. VR solutions, especially mobile VR, require high bandwidth and low latency networks, where adapting 5G networks [4] can be beneficial. Advanced visual tracking techniques [5] are important for the development of the VR technology as they may help alleviate the VR sickness symptoms.

Technological maturity and economical affordability are two factors for the current attention and success of the VR solutions. VR technologies are already emerging as a mature technology, being an important part of the future technologies ecosystem while also having an important economic impact [6].

A VR system consists of a VR head-mounted display device (VR HMD), a head and/or body tracking system, interaction devices, and a processing subsystem. The graphical fidelity and the overall low latency of the system are especially important for achieving a good user experience. Current VR systems can be divided into four categories: (i) high-performance VR tethered solutions, (ii) stand-alone VR untethered solutions, (iii) mobile VR, and (iv) gaming VR solutions. Key high-performance commercially-available

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solutions are the Oculus Rift CV1 [7], HTC Vive [8] and open source OSVR [9]. A common requirement for all tethered VR solutions is a need for an external high-performance PC system that runs the necessary software. Oculus Go [10] is an example of a stand-alone VR headset. Mobile VR solutions are very popular, because they utilize smartphones for display and processing, offering a more affordable and portable alternative. Key representatives of Mobile VR are the Google Daydream [11] and the Samsung GearVR systems [12]. Gaming VR solutions use video gaming consoles for processing. Currently the commercially-available representative of this group is the Sony PSVR [13].

User experience (UX) of a VR solution encompasses users' entire perceptual, emotional, and cognitive interaction with the device. For a successful and generally accepted VR solution, UX is one of the most important features together with technological maturity and affordability.

One of the key challenges when designing and using VR solutions is the potential phenomenon of the VR sickness, where some users may suffer from symptoms like nausea, headache, and dizziness from usage [14]. VR sickness is also known by other names based on the causes of the symptoms, such as motion sickness [15], cybersickness [16], and simulator sickness [17]. A more general term "VR sickness" or just "sickness", not restricted by specific causes, is therefore proposed in reference [14].

VR sickness can be observed and measured by different approaches and the Simulator Sickness Questionnaire (SSQ) presents one of the commonly used standardized method of subjectively assessing these effects [18]. On the other hand, a more objective measure of VR sickness is to monitor the responses of the autonomic nervous system of the user, i.e. the users' psychophysiological parameters. Measurements of parameters, such as the heart rate, breathing rate and amplitude, pupil dilatation, (facial) skin temperature and conductance level and response, can give another insight into VR sickness [19].

In this study we present the influence of the video content type (neutral vs action content) on the perceived VR sickness. Additionally, the effect of technology of panoramic 3D displays on the perceived VR sickness was studied - five video display types were used – a 2D TV set, three generations of the Oculus Rift VR HMD, and the mobile VR solution Samsung Gear VR. The VR sickness was assessed using the SSQ and by measuring users' heart rate level, respiratory rate, skin temperature and conductance response.

The research questions were:

- What is the influence of the video content type on the VR sickness perception and physiology of the user?
- What is the influence of the video playback device in terms of technology (2D vs 3D display, VR HMD display

quality) on the VR sickness perception and physiology of the user?

Key contributions of the paper are:

- effects of video content type on the users' VR sickness response were confirmed;
- effects of the display type (device) on the users' VR sickness response were confirmed;
- VR sickness response, measured by means of the SSQ and physiology was evaluated.

2 Related works

VR sickness presents an important challenge when designing VR applications. Its effects are similar to motion sickness and can, to various degrees, result in a variety of unpleasant symptoms such as nausea, headache, disorientation, and dizziness [20]. In current studies VR sickness is measured by various validated and non-validated questionnaires, by monitoring body kinematics or postural sway, and by recording the physiology of the user. Additionally, the effects of different display type and rendering modes (e.g. stereoscopic or monoscopic) are researched [25]. The effects of visual displays on users are not yet well understood, and application aspects of design itself (which might induce VR sickness) may be of greater importance. One of the findings was that the Disorientation factor (SSQ-D) of the SSQ questionnaire is especially prominent when measuring cybersickness in VR systems [20, 21, 23].

The affordability of VR systems opens new questions on the effects of its long-term use. These effects were researched in a study [21] where the participant was exposed to an immersive VR setup for 24 h. The results show a significantly increased SSQ score (especially the SSQ Disorientation) when the participant was immersed in the VR environment [19, 21]. This indicates the potential impact of VR sickness effects on the users.

Panoramic videos (otherwise known as 360° or omnidirectional videos) are a new type of immersive media specially designed for use in VR systems. 360° panoramas enable a user experience closest to reality, as measured by users' psychological responses, and their physiological responses [22]. Panoramic scenes and videos were found to be important features of virtual reality in imitating the experience of physical environments [22]. Measurements on the quality of user experience in conjunction with VR sickness with panoramic videos is described in [23]. Panoramic video content of various quality (4 k UHD vs HD) and degrees of motion (high, medium and low) were used to assess the simulator sickness in different head mounted VR displays. Results showed that in

terms of sickness the HTC Vive performed better than the Oculus Rift. In addition, the SSQ Disorientation factor was again the most dominant factor [23].

Focusing specifically on the VR sickness, research using an action type of video content (the rollercoaster ride) is presented in [24]. The study's results indicate that the more realistic rollercoaster simulation (higher levels of graphical fidelity and realism), the higher chance of inducing VR sickness. Therefore, one can expect that the video content type and its realism to have an effect on users' VR sickness perception. Only one VR HMD type was used in the specific study, however. In another, study participants (pain patients) experienced higher levels of VR sickness using the HMD compared to the table-mounted display. Although motion sickness effects were also experienced in the stereoscopic desktop condition, they were less frequent. On the other hand, HMD enabled patients to move their heads, while the immersive desktop display had to be peered into, allowing less head movement [25].

The Simulator Sickness Questionnaire (SSQ) [18] is a standard questionnaire-based method for assessing motion sickness, extensively used for assessing VR sickness [20, 21, 23]. Filling-in the SSQ, the participants describe their sickness perception according to 16 symptoms of simulator sickness (rating them from 0 (none), 1 (slight), 2 (moderate) to 3 (severe) level). Symptoms included in SSQ are general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, blurred vision, dizzy eyes open, dizzy eyes closed, vertigo, stomach awareness, and burping. Scores are divided into three subsections: nausea, disorientation, and oculomotor. The resulting SSQ total score estimates the overall level of simulator sickness. As an example, a total SSQ score greater than 20 represents significant simulator sickness, whereas scores less than 5 indicate negligible symptoms [26].

3 Experiment design and procedure

We present the participants' information, apparatus, metrics, experiment setup environment, tasks, and experiment procedure.

3.1 Participants

We recruited 15 healthy volunteers for the experiment. 13 were male and 2 female, with an average age of 27.2 years ($SD = 6.8$ years). The youngest was 20 and the oldest 36 years old. As the VR technology is relatively new, we were interested in the participants' background, previous experience with technology, computers and gaming, and especially with VR/AR devices. Previous technology experience was assessed by which and how often the participants used specific devices.

3.2 Measuring set-up

The participants watched two omnidirectional stereoscopic 3D videos of different video content: i) neutral video (relaxing tropical beach) and ii) action video (rollercoaster ride). The first being an example of emotionally neutral or pleasant content with low motion of the objects and the latter emotionally more arousing (stress, fear, anxiety) with higher motion content. The videos were 110 s long and encoded in 4 k resolution and 60 Mbit/s.

Five different VR 360 video playback device (display type) setups were used (Table 1):

To avoid any differences in video playing due to the different technical setups, high-performance gaming computers with uniform specifications (7700 K Intel core i7 CPU, 16 GB DDR 43000 MHz, Samsung Evo 850 SSD, Nvidia 1070 GPU) were used for all display devices to ensure smooth video playback. Each video playback device was connected to a dedicated computer. In mobile HMD, to guarantee adequate performance the video was saved to the internal flash memory, which operates with a similar technical performance to a PC SSD drive.

To simulate the 360° VR experience also on the 2D TV, the headset was used as the steering wheel to enable participants to select the video view on the TV screen.

For audio playback semi-open studio headphones AKG K141 were used. Neutral video contained relaxing music, and the action video contained realistic rollercoaster noises.

Physiology of the participant was monitored on the non-dominant hand by using a multiparameter measuring system MP150 (by Biopac Inc., USA). The device sampled (1 kHz): i) skin conductance (skin conductance level (SCL) and skin conductance response (SCR)) using wet reusable electrodes attached to the distal phalanges of the pointer and middle finger, ii) skin temperature using a fast thermistor on the little finger, iii) breathing rate using an elastic torso belt and iv) heart rate using a sensor on the ring finger.

3.3 Metrics

VR sickness was assessed using the SSQ and the measurement of participants' physiology response while they watched different omnidirectional video clips by means of different playback devices. The environmental conditions (same room temperature and relative humidity, room furniture, equipment) were controlled.

As a measure of participant's perception of VR sickness the Simulator Sickness Questionnaire was used. As a more objective measure of participant's VR sickness the physiology was acquired. Physiological data was processed using the Acqknowledge 4.1 software (by Biopac Inc., USA) and SPSS 25 (by IBM, USA). The acquired data was filtered (moving artefacts removed) and processed using

Table 1 Video playback devices (display type)

Device	Description
TV	55" TV set LG OLED 55 C6V 2D display, resolution 4 k, OLED matrix
DK1	first pilot VR HMD Oculus Rift DK1, resolution 1280 × 800@60 Hz
DK2	second pilot VR HMD Oculus Rift DK2, resolution 1920 × 1080@75 Hz
CV1	first commercial VR HMD Oculus Rift CV1, resolution 1080 × 1200@90 Hz per eye
SG	mobile VR HMD Samsung GearVR with Samsung Galaxy Note 4, resolution 2560 × 1440@60 Hz

Acqknowledge's built-in algorithms. I.e. respiration rate, skin conductance level (SCL) and skin conductance response (SCR) were calculated during watching the video clips. Changes of physiological parameters were calculated as difference to the baseline level, whereas baseline was defined as a period of 30 s of relaxed state prior the video watching.

3.4 Tasks and procedure

Initially, the volunteers were informed about the subject and goals of the study and explained the procedure. After the consent for the experiment was signed, participants' demographics, technology preferences, eye-sight information (e.g. use of glasses or lenses) were collected. The experiment was performed sitting on a sofa with the non-dominant hand with attached physiology sensors resting on the arm-rest (Fig. 1). During the entire experiment, the participants' physiology was recorded. Two researchers took part in conducting the study, one interacting with the participant and another operating the equipment.

The omnidirectional 360 videos were played for different participants in a preselected Latin square order to ensure an appropriate randomization of tasks. Additionally, each participant watched two video clips on five devices in a randomized order of presentation of the neutral and action video. Immediately after watching each clip, the participants were instructed to fill-in the SSQ questionnaire. The experiment concluded with a short interview to gather participants' feelings and feedback.

**Fig. 1** Participant during the experiment

4 Results

The Shapiro-Wilk test showed a non-Gaussian distribution of data, therefore the non-parametric Friedman and Wilcoxon signed rank tests were used for comparisons within the analysis.

The participants were of mixed background, their occupation ranging from technical to social sciences, with an average proficiency in Internet, computer and mobile device usage. We were interested into participants' previous technology experience and typical usage. On average, they reported using the mobile phones up to 2 h per day, mostly for calls and text messages, e-mail, news reading, entertainment and gaming. Four of them were active gamers, using PC and video consoles. Three of the participants had previous experience (used at least once) with the VR devices (namely, GoogleVR, Oculus Rift, Microsoft Hololens).

4.1 SSQ questionnaire

SSQ results for all conditions are presented in Table 2. The scores are shown for all SSQ subscales (Nausea, Oculomotor, Disorientation) and Total SSQ Score) for both video content types (neutral, action). The results show the SSQ scores for the TV, three generations of Oculus Rift VR HMDs and the mobile Samsung GearVR HMD (descriptions are written according to Table 1).

Additionally, a comparison of the Total SSQ score of the neutral and action content for all conditions is illustrated in Figs. 2 and 3.

Figures 2, 3 and 4 indicate the largest difference in scales between all devices (display type) while viewing video content via TV over four other headsets, with the TV display type giving lowest values. The SSQ scores for the TV display type are comparable for both video content types. The differences for the VR HMDs display types between video content types are larger and are especially apparent from Fig. 4.

From the Table 1 and Fig. 3 the SSQ-Disorientation scale is clearly dominant. This is consistent with the findings of other studies [20].

A statistical analysis has been performed to illustrate the statistically significant differences. Statistically significant differences ($p < 0.05$) were found for both types of video content

Table 2 SSQ average score results for all conditions

SSQ score	display type	neutral content		action content	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Nausea	TV	3.180	8.583	5.088	10.113
	DK1	12.084	10.492	26.076	22.364
	DK2	5.088	7.090	33.072	30.990
	CV1	10.176	12.210	38.796	36.677
	SG	19.080	21.332	28.620	28.620
Oculomotor	TV	4.548	8.499	5.559	10.116
	DK1	19.708	18.743	31.331	23.252
	DK2	12.633	15.069	34.868	35.065
	CV1	15.665	17.301	29.309	28.631
	SG	26.783	18.315	34.363	29.755
Disorientation	TV	3.712	8.263	4.640	11.366
	DK1	19.488	20.913	55.680	48.220
	DK2	10.208	13.379	53.824	55.647
	CV1	17.632	20.691	51.040	61.731
	SG	27.840	26.827	47.328	49.299
Total Score	TV	4.488	8.021	5.984	10.272
	DK1	19.697	17.224	40.641	29.206
	DK2	10.971	12.522	44.631	42.630
	CV1	16.456	17.588	43.384	43.335
	SG	28.175	22.300	40.891	36.329

when comparing the SSQ results (all four SSQ scales) on different display types (Table 3). The results confirm that there are important differences in experiencing when using different video devices (display type).

Furthermore, statistically significant differences ($p < 0.05$) were found when comparing the influence of the content type (Table 4). Friedman’s test confirmed this as the content difference was statistically important on every SSQ scale except the Oculomotor scale. The results show that the content type has a significant influence on the VR sickness effects perception.

We were interested in the difference among different display types. A pairwise comparison between the combinations

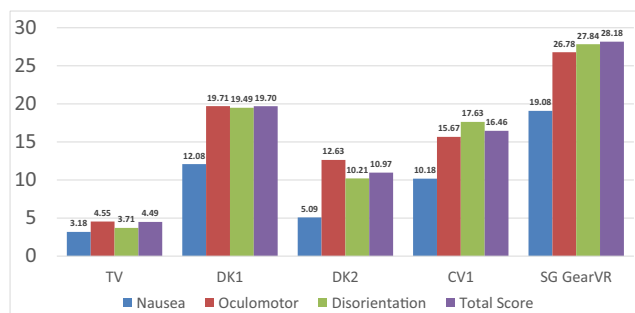


Fig. 2 Total SSQ average score results for the neutral content on all devices (display type)

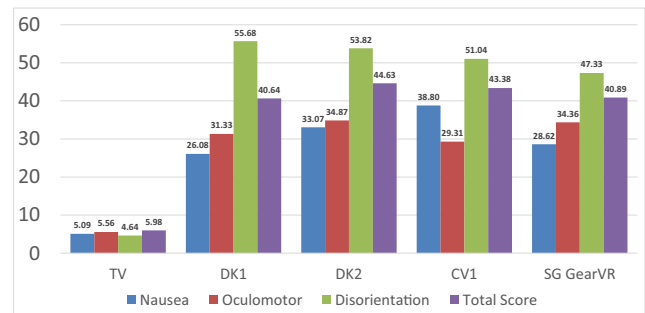


Fig. 3 Total SSQ average score results for the action content on all devices (display type)

of all display types (Wilcoxon signed rank test) for the total and disorientation SSQ scores for the “neutral” and “action” content, is shown in Tables 5 and 6. There are statistically significant differences in experiencing between the TV display type and VR HMDs.

4.2 Physiology

To further understand VR sickness effects, we measured physiological responses (skin conductance, heart rate, skin temperature, respiration rate) of the participants. We were interested in the response influenced by using different video content types as well as display types.

4.2.1 Video content type

An example of the physiological response of a participant is shown in Fig. 5. In Fig. 5 top, the response for a neutral content video and in Fig. 5 bottom, the response for the action content is presented.

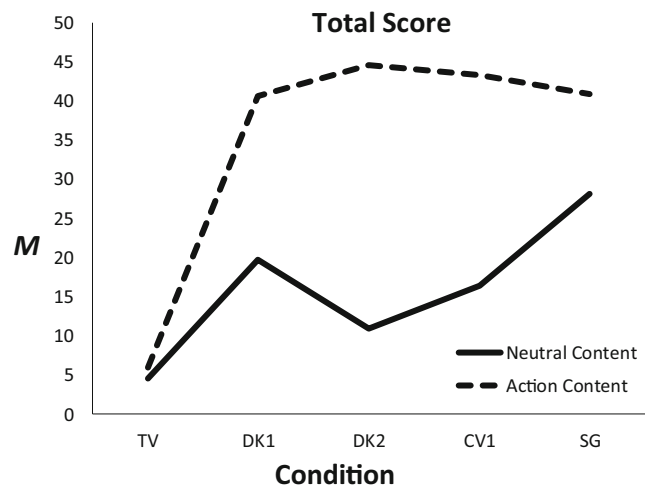


Fig. 4 Total SSQ score comparison for the “neutral” and “action” content on all devices (display type)

Table 3 Display type differences (Friedman test)

	neutral content		action content	
	χ^2	<i>p</i>	χ^2	<i>p</i>
Nausea	16.257	0.003*	19.413	0.001*
Oculomotor	22.482	0.000*	20.190	0.000*
Disorientation	18.245	0.001*	20.000	0.000*
Total Score	23.585	0.000*	19.972	0.001*

**p* < 0.05

From our results we can conclude that during different content types of video clips the physiology indeed changed as expected. For example, in Fig. 5 top, one can observe the slow decrease of skin conductance level, the absence of SCR pulses, and a stable heart rate and respiration rate, which is typical for relaxation and relaxed state of the participant. In Fig. 5 bottom, the reactivity of heart rate, respiration rate and electrodermal activity is much higher (see the number of SCR pulses, marked by a water drop mark).

Under the condition of a neutral video content type, statistically significant correlations were observed between the SCL response and SG VR headset (SSQ Oculomotor (*r* = -0.574; *p* < 0.05), Disorientation (*r* = -0.605; *p* < 0.001) and Total Score (*r* = -0.540; *p* < 0.05)).

In an action video content type condition, statistically significant correlations were observed between the SCL response and the SG VR headset on all SSQ scales (SSQ Nausea (*r* = -0.540; *p* < 0.05), SSQ Oculomotor (*r* = -0.608; *p* < 0.05), SSQ Disorientation (*r* = -0.541; *p* < 0.05) and SSQ Total Score (*r* = -0.593; *p* < 0.05)).

4.2.2 Display type

From the results, we can state that the neutral video clip was more relaxing for participants than the action video clip - the levels of most physiological parameters during the neutral video clip did not differ significantly from the baseline level. The HR level and the number of SCR pulses when watching neutral video decreased, indicating higher relaxation of the participants as compared to baseline. A possible explanation

Table 4 Content type differences (Friedman test)

	content type	
	χ^2	<i>p</i>
Nausea	10.286	0.001*
Oculomotor	5.333	0.210
Disorientation	6.231	0.013*
Total Score	10.286	0.001*

**p* < 0.05

can be found in that the neutral video contained a calm tropical beach video clip with relaxing music. No statistically significant differences were observed between playback devices (display type). The only parameter where the display type affected the change was SCL, although insignificantly (Fig. 6).

5 Discussion

Our research studied the effects of VR technology and video content type on the perceived VR sickness effects and physiology of the user.

5.1 Technology influence

The observed SSQ scores were the lowest for the TV screen for both content types, and higher, when VR HMDs were used. Statistically significant differences for the Total SSQ score (Table 4) were found when comparing various device combinations for the neutral video (DK1-TV, CV1-TV, SG-TV, DK2-DK1, SG-DK1 and SG-DK2) and the action video (DK1-TV, DK2-TV, CV1-TV, SG-TV and CV1-DK1). Specifically, when comparing the SSQ Disorientation score, statistically significant differences were found when comparing various device combinations for the neutral video (DK1-TV, CV1-TV, SG-TV, and SG-DK2) and the action video (DK1-TV, DK2-TV, CV1-TV, and SG-TV). We can conclude that the selection of the technology of the VR playback device (HDM) was an important factor for participants’ perception of VR sickness and can generalize that watching of a video using VR HDM devices in general causes more sickness than watching of a video on a TV screen.

According to the study in [26], the scores below 5 indicate negligible signs of VR sickness, while the scores above 20 indicate significant signs. Similar to other studies [20, 26] the Total score of SSQ and especially the SSQ-Disorientation scale, as shown in Fig. 3, proved to be an important tool for VR sickness estimation.

Physiology, as an objective measure of the psychological state of the participant, turned out not to be such a reliable parameter for assessing VR sickness. The change of physiology when watching video on a TV screen had was similar to the usage of other playback devices. No statistically significant differences between other playback devices (display type) were found. The neutral video clip was more relaxing for participants than the action video.

5.2 Video content influence

The lowest VR sickness total SSQ score (4.488) was measured in the neutral video content condition displayed on the TV screen. The total SSQ score for the action content (5.984)

Table 5 Total SSQ score comparison of playback devices for the neutral and action video content (Wilcoxon signed rank test comparison)

Display type	Total SSQ score (neutral content)		Total SSQ score (action content)	
	Z	p	Z	p
DK1 - TV	-2.676	0.007*	-3.235	0.001*
DK2 -TV	-1.791	0.073	-3.174	0.002*
CV1 - TV	-2.094	0.036*	-3.185	0.001*
SG - TV	-3.192	0.001*	-2.943	0.003*
DK2 - DK1	-2.049	0.040*	-0.220	0.826
CV1 - DK1	-0.563	0.574	-2.062	0.039*
SG - DK1	-2.173	0.030*	0.000	1.000
CV1 - DK2	-1.253	0.210	-0.421	0.674
SG - DK2	-2.713	0.007*	-0.740	0.459
SG - CV1	-1.805	0.071	-0.094	0.925

* $p < 0.05$

on the TV screen was the second lowest total SSQ score, an expected result. The highest total SSQ score (44.631) was measured for the action content on the Oculus Rift DK2 HMD. The observed SSQ scores were consistently higher in case of the action video content on all SSQ scales. When observing the Disorientation SSQ scores, the differences between the devices and content types are even more apparent. The Disorientation SSQ scores were higher than Total SSQ scores for the action video content type for the VR display type.

The results show that the type of video content (neutral vs. action) influenced the participants' perception of VR sickness and their physiology. In addition to the SSQ questionnaire, the individual user experience was monitored through physiological measures. We were interested in the extent to which changes in physiology correlate with a feeling of a well-being and one's annoyance/inconvenience level, indicated by the SSQ. We found that skin conductance level

significantly correlates with Oculomotor, Disorientation, and the Total score of SSQ when watching neutral video content using the SG. The Direction was negative, indicating individuals having a significantly higher conductance reported significantly lower changes in experience. In the conditions where action and neutral video clips were individually played, the measurements of user experience were linked to skin conductance. The direction of relationship for the action clip was the same as when watching the neutral clip. An important link was observed on all SSQ scales when watching with SG. Other than skin conductance, with other physiological measures, no statistically important correlations were observed.

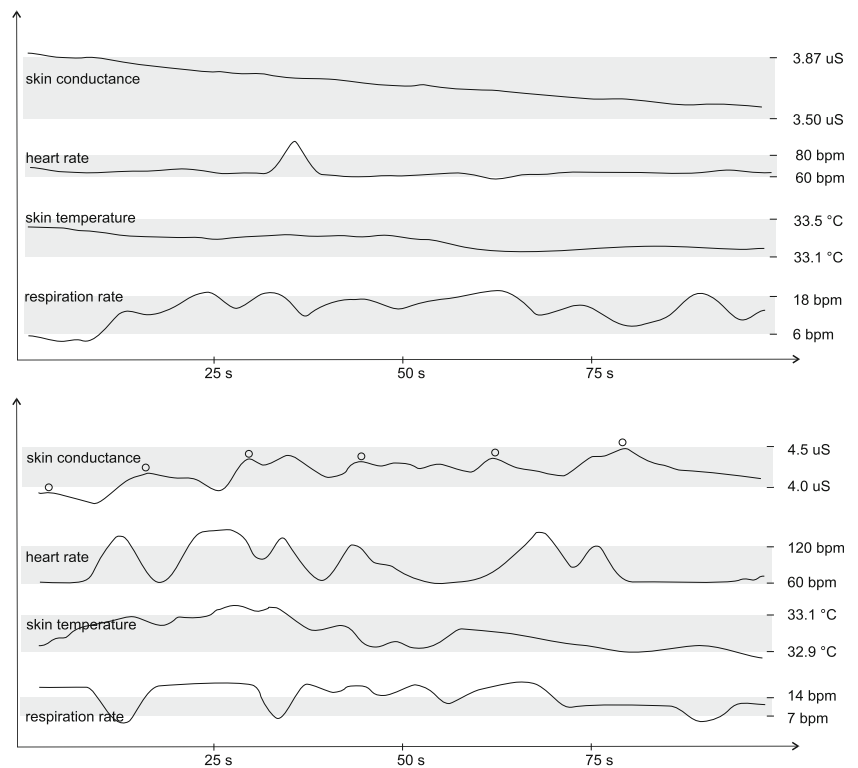
On the basis of our results, one could deduct that the skin conductance level is the physiological measure that best correlates with the scales on the SSQ questionnaire when watching videos through the SG device. Other physiological parameters, i.e. SCR pulses, heart rate and respiration rate, had no statistically significant correlation with scales of SSQ.

Table 6 Disorientation SSQ score comparison of playback devices for the neutral and action video content (Wilcoxon signed rank test comparison)

Display type	Total SSQ score (neutral content)		Total SSQ score (action content)	
	Z	p	Z	p
DK1 - TV	-2.506	0.012*	-3.219	0.001*
DK2 -TV	-1.823	0.068	-2.941	0.003*
CV1 - TV	-2.161	0.031*	-2.442	0.015*
SG - TV	-2.826	0.005*	-2.675	0.007*
DK2 - DK1	-1.941	0.052	-0.878	0.380
CV1 - DK1	-0.054	0.957	-0.679	0.497
SG - DK1	-1.889	0.059	-0.809	0.418
CV1 - DK2	-1.807	0.071	-0.618	0.537
SG - DK2	-2.552	0.011*	-1.035	0.301
SG - CV1	-1.357	0.175	-0.052	0.959

* $p < 0.05$

Fig. 5 Physiology (top - neutral video clip, bottom - action video clip) - time series (top to bottom) of skin conductance (in microsiemens), heart rate (in beats per minute), skin temperature (in °C) and respiration rate (in breaths per minute). In Fig. 5 top (neutral video) the effect of a motion artefact is visible on a respiration rate scale, while in Fig. 5 bottom (action video) the SCR events are marked on a skin conductance scale (water drop mark)



5.3 Study limitations

The primary limitation of this pilot study is the relatively small population. However, the statistical results when comparing the display type and content types (Tables 3 and 4) show significant differences with high probability. Moreover, there are comparable other studies based on similar relatively low user study populations [27–31], showing good results. It should be noted that participants' anxiety, which could result in changes of physiology resulting from the participants being made aware of being under observation [33], were neglected.

A gender imbalance could be a limitation; however relevant studies show [32] that possible gender differences in visually induced motion sickness scenarios are not due to gender differences but more of susceptibility.

The selection of the video clips and their resulting perception could be argued. Our general intention was to use two very distinctive video contents, one relaxing, and the other, highly reactive in psychophysiology. We defined a “neutral” video content type as slow motion/dynamic video and the “action” video content type as high motion/dynamic video. Under the term “motion”, we considered both camera and content motion. This approach has been shown successful in other studies [23]. The technical parameters of the video have been carefully studied. A selection of panoramic 3D video content has been shown as a good choice when assessing psychological and physiological responses in the VR environment [22]. Furthermore, the choice of the rollercoaster ride as a high motion/dynamic video content

type (in contrast to a low motion/dynamic video content type), has been shown relevant in other studies [24].

Following the same principle, in parallel to a VR experience, sound was used and the selection of sounds could be argued in the same manner as the video content.

The future studies will include new VR devices and observation of additional physiological parameters, e.g. heart rate variability with SDNN and RMSSD, pupil dilatation and facial thermography.

6 Conclusions

The results of our experiment showed that the video content type in a VR environment is an important factor for the user experience and perception of VR sickness. It affects the SSQ grading and partly physiology of the user (most notably skin conductance). Additionally, the effects of different generations of VR technology were studied and conclusions made. VR sickness perception was significantly less affected by TV display type than by other VR HMD.

Apart from the skin conductance level (SCL), physiology was not found to be a significant measure for VR sickness assessments.

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Display type

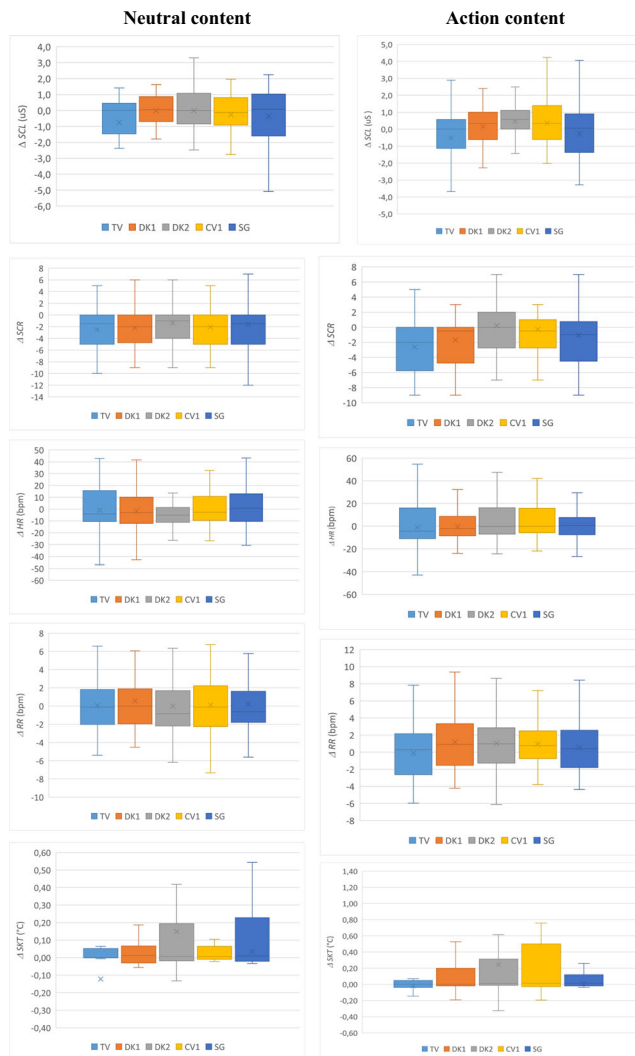


Fig. 6 Box plots of physiology changes during watching the videos using different playback devices (display type); left – neutral video clip, right – action video clip

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest.

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