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Part 393: Structured literature review of visually induced motion sickness during watching electronic images

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Foreword

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

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A list of all parts in the ISO 9241 series can be found on the ISO website.

Introduction

Recent advancements in moving image technology have enabled us to view and interact with images using various display devices and in various ways. Moreover, application fields are not limited to entertainment but also to other business scenarios with the expectation to expand to more ambitious applications.

In terms of the expansion of application fields and utility forms, the role of video images serving society has become increasingly important. Thus, it has become necessary to consider the ergonomic aspects of utilizing video images in view of further progressive expansions. In relation to ergonomic aspects, we need to consider not only the specifications of devices but also those affecting image safety, including those for reducing visually induced motion sickness, or VIMS. VIMS, which is similar to motion sickness, is usually recognized as simply being a minor annoyance from which those being affected would recover in the short term. However, some people experiencing this sickness suffer from vomiting or ataxia, and thus, are incapacitated.

Yet, the ambitious production of moving images and the use of those images should not be hindered by considerations to reduce VIMS. Major factors causing VIMS are considered to be visual motion of various kinds in moving image. In addition, visual motion in moving images conveys various types of information, for example, the psychology of characters captured by camera work producing various types of visual motion. For moving images shown to the public and those produced by professional staff, VIMS is presumed to be carefully considered based on empirical knowledge. Besides, adventurous trials can sometimes be necessary to drive forward ambitious moving image production and the use of those images. Moreover, in the absence of empirical knowledge, the uncharted territory of visual effects can come into existence through technical innovations. Although image safety is naturally important, these progressive approaches should not be fully restrained. The issue can be addressed by advancing moving image technology based on an understanding of the characteristics of VIMS. Thus, it is highly important to accumulate scientific knowledge on VIMS. This will encourage attempts to ambitiously produce moving images while considering image safety, which can be expected to lead to further development in the effective use of moving images.

With a view to international standardization for reducing the incidence of VIMS, this document attempts to summarize the scientific knowledge of VIMS by presenting an effective procedure for developing an advanced understanding of VIMS. This is achieved from the viewpoint of empirical knowledge on VIMS obtained during the production of moving images. This document categorizes related scientific knowledge on the ergonomic characteristics of VIMS, and clarifies the conditions under which VIMS can be induced and ways to reduce it. These actions are expected to develop the basis for ambitious moving image production and the use of these images. Furthermore, the work is expected to provide effective and basic data to allow VIMS to be studied together with a discussion of the guidelines focusing on VIMS.

While this document basically focuses on scientific knowledge of VIMS, postural ataxia or disorientation as an aftereffect of visual exposures especially to virtual environment, is another related issue and is even more important from the viewpoint of safety in daily life. However, this document cannot directly deal with the issue because of shortages of scientific reports on it. This should be further examined, and scientific knowledge of the characteristics should be accumulated.

This document does not include any guidelines. Moreover, this document is based on up-to-date data of the ergonomic characteristics of VIMS and can be revised as new scientific data become available.

Ergonomics of human-system interaction —

Part 393: **Structured literature review of visually induced motion sickness during watching electronic images**

1 Scope

This document gives the scientific summaries of visually induced motion sickness resulting from images presented visually on or by electronic display devices. Electronic displays include flat panel displays, electronic projections on a flat screen, and head-mounted displays.

Different aspects of human-system interaction are covered in other parts of the ISO 9241 series (see Annex A).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
visually induced motion sickness
VIMS
motion sickness-like symptoms induced by perceived motion within the visual environment, such as when watching movies and screen images of video games

Note 1 to entry: The symptoms may include *dizziness* (3.2), *vertigo* (3.3), sweating, odd feelings in the stomach, and nausea which can progress to vomiting.

3.2
dizziness
physical unsteadiness, lack of balance or light-headedness

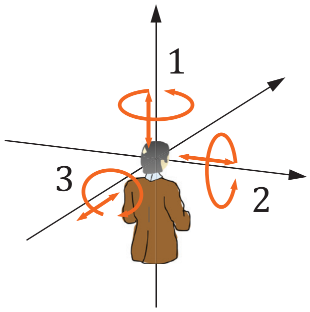
3.3
vertigo
sensation of rotation or movement of oneself (subjective vertigo), or of rotation or movement of one's surroundings (objective vertigo), in any plane, caused by diseases of the inner ear, or by disturbances of the vestibular centres or pathways in the central nervous system

3.4
postural ataxia
inability to coordinate voluntary movements for maintaining posture, caused by dysfunction to sensory nerve inputs, motor nerve outputs, or the processing of them

3.5
disorientation
loss of sense of direction, position or relationship with the surroundings

3.6
global image motion
wide spatial range of visual motion composed of different velocities and directions that are systematically aligned in a moving image

Note 1 to entry: There are generally six types of global image motion that correspond to the different types of motion of a camera during the shooting of images. These are rotation around and translation along the pitch, yaw, and roll axes (see Figure 1).



Key
1 yaw
2 pitch
3 roll

Figure 1 — Rotations around and translation along the three axes

3.7
vection
self-motion perception induced by visual motion

Note 1 to entry: Vection can be categorized into two different types: linear vection and circular vection. Liner vection consists of linear self-motion perception, while circular vection consists of circular self-motion perception around either one or several of the yaw, pitch, and roll axes.

3.8
design field of view
design FOV
angular region subtending the active area of a display as designed to be observed from the viewing position

4 Theories of visually induced motion sickness

Although the specific mechanism of VIMS has not been clarified, there are several hypotheses to explain the cause of motion sickness (MS) including VIMS. Major hypotheses of MS are:

1) sensory conflict theory, or sensory rearrangement theory;

2) poison theory; and

3) postural instability theory.

The sensory conflict theory (Reason and Brand, 1975) explains the cause of MS as the mismatch among different types of sensory information, and even within single modalities of this information, such as visual, vestibular, proprioceptive, etc.

The sensory rearrangement theory suggests that sickness occurs when the pattern of sensory information containing signals from multi-modal senses and those within a single modal sense do not match the patterns of those stored in the central nervous system, or CNS, from past experiences. As a modified version of this sensory rearrangement theory, the theory that focuses on sensory mismatch of the subjective vertical is known as subjective vertical theory. The sensory rearrangement theory holds that the severity of sickness increases when the discrepancy between the pattern of sensory information signals and those stored in CNS becomes larger. When we consider and clarify the meaning of "mismatch" among different senses, it leads to the sensory rearrangement theory, which is widely accepted among researchers. In general, the sensory rearrangement theory is often referred to as sensory conflict theory.

The poison theory (Treisman, 1977) is used to explain why MS arises. The idea is that MS was developed collaterally for organisms to survive in the course of evolution. According to the theory, when emesis was established as a reaction to intoxication by poison, organisms developed a process in which dizziness and vertigo, and then postural instability, is induced while the gastrointestinal tract is being emptied by producing mismatch signals among the visual, vestibular, and proprioceptive modalities. Because of this process, emesis is induced without the ingestion of poison by actual mismatch between the different types of sensory information. This theory is interesting but difficult to examine and it generally does not contradict other theories trying to explain the mechanism of VIMS.

The postural instability theory (Riccio and Stoffregen, 1991) explains the cause of MS as the state of postural instability. Organisms try to keep postural stability in accordance with their environment in daily activities. The stable state can be obtained by reduce body fluctuations to the smallest, while remaining fluctuations cannot be fully controlled. According to the theory, sickness occurs when a stable state cannot be obtained. Moreover, the severity of sickness can be determined by the time the body remains in the unstable state. There are various discussions, both from positive and negative sides, on this theory.

5 Measurement of visually induced motion sickness

Measurement methods of VIMS can be mainly categorized as subjective measures of symptoms or physiological recordings including those of autonomic nervous activities. Subjective measures can be basically classified into two categories:

1) evaluation of sickness severity with one axis scale; and

2) evaluations of various symptoms related to the sickness, which are then used to obtain a total score and several sub-scores.

The measurements required to evaluate one value of sickness severity can be obtained in a short time. Then, those measurements can be carried out while participants are exposed to stimuli of VIMS during experiments. These kinds of measurements were proposed by various researchers who used different scales. Thus, it is rather difficult to directly compare the data obtained in different experiments by different researchers. The scales can be different in light of:

a) the number of points of the scale,

b) the level of severity indicated by the largest score, and

c) the kind of symptom levels attributed to each score of the scale.

The number of points on the scale is inconsistent: some of them have 20, and others have 11, 7, 6, and 4. Keshavarz and Hecht (2011a) proposed a fast motion sickness scale (FMS), which is a 20-point rating scale ranging from zero (no sickness at all) to 20 (frank sickness). They examined and found high correlations with the simulator sickness questionnaire (SSQ), total score (r = 0,79) and sub-score (r = 0,83). They also used it in another experiment (Keshavarz and Hecht, 2011b).

There are two different, but comparable, scales adopting 11-point levels of scoring. One is called the misery scale (MISC), which has been used by Bos and his colleagues (Bos et al., 2005; Lubeck et al., 2015; Lubeck et al., 2016). The scale was revised from the one adopted by Wertheim et al. (1998), based on “the knowledge that nausea is generally preceded by other symptoms such as dizziness, headache, (cold) sweat, and stomach awareness” (Bos et al., 2005). The MISC with symptom description for each score is shown in Table 1. The other is the sickness related scale, focusing on the symptoms felt in the head, and of dizziness and nausea (Ujike et al., 2004; Ujike et al., 2005). The scale is presented in Table 2.

Table 1 — Misery scale (MISC)

Symptom	Severity	Score
No problems		0
Uneasiness (no typical symptoms)		1
Dizziness, warmth, headache, stomach awareness, sweating, and	vague	2
other symptoms	slight	3
	fairly	4
	severe	5
Nausea	slight	6
	fairly	7
	severe	8
Retching		9
Vomiting		10

Table 2 — Sickness related scale

Symptom description	Rating
No problems	0
Feeling very slight unusual sensation	1
Feeling slight unusual sensation	2
Tendency to feel unusual sense in the head	3
Sometimes feeling unusual sense in the head	4
Feeling unusual sense in the head	5
Tendency to feel sick and dizziness	6
Feeling slight sick and dizziness	7
Feeling sick and dizziness	8
Feeling very sick and dizziness	9
Cannot see visual motion, or feel vomiting	10

A 7-point scale is used in several reports (Webb and Griffin, 2002; Webb and Griffin, 2003; Lo and So, 2001; So et al., 2001; Ji et al., 2009), and attributes symptom levels to each score as:

— 0 = no symptoms;

— 1 = any unpleasant symptom, however slight;

— 2 = mild unpleasant symptom;

— 3 = mild nausea;

— 4 = mild to moderate nausea;

— 5 = moderate nausea, but can continue;

— 6 = moderate nausea, want to stop.

A 6-point scale is used by other researchers (Bijveld et al., 2008; Golding et al., 2009), of which the scale indicates the symptoms as:

— 1 = no symptoms;

— 2 = initial symptoms, but no nausea;

— 3 = mild nausea,

— 4 = moderate nausea (stop motion);

— 5 = severe nausea;

— 6 = vomiting.

A 4-point scale was produced by Bagshaw and Stott (1985) and is used by some studies (Clemes and Howarth, 2005; Diels and Howarth, 2011; Diels and Howarth, 2013), of which the range is:

— 1 = no symptoms;

— 2 = mild symptoms, but no nausea;

— 3 = mild nausea;

— 4 = moderate nausea.

Another 4-point scale, which simply indicates “general discomfort”, one of the 16 items adopted in SSQ, was used by others (Ujike et al., 2005b).

To date, several different methods have been proposed for scoring, with the evaluation of multiple symptoms. One of these methods uses the Graybiel scale of MS (Graybiel et al., 1968). Alternative forms of the method have been derived. The Graybiel scale has 7 categories of symptoms for evaluating MS (see Table 3). For each of the categories, the severity of symptoms is evaluated, and then a total score is obtained (Hu et al, 1989; Andre et al., 1996). Depending on the total score, the level of severity of MS can be categorized as being one of five different levels.

Table 3 — Categories and levels of severity of the Graybiel scale

Category	Pathognomonic 16 points	Major 8 points	Minor 4 points	Minimal 2points	AQS[a] 1 point
Nausea syndrome	Vomiting or retching	Nausea II[c], III[b]	Nausea I[d]	Epigastric discomfort	Epigastric awareness
Skin colour		Pallor III[b]	Pallor II[c]	Pallor I[d]	Flushing
Cold sweating		III[b]	II[c]	I[d]	
Increased salivation		III[b]	II[c]	I[d]	
Drowsiness		III[b]	II[c]	I[d]	
Pain					Headache
Central nervous system					Dizziness: Eyes closed ≥II[c] Eyes open III[b]
Levels of severity identified by total points scored					

[a] Additional qualifying symptoms.

[b] Severe or marked.

[c] Moderate.

[d] Slight.

Table 3 *(continued)*

Category	Pathognomonic 16 points	Major 8 points	Minor 4 points	Minimal 2points	AQS[a] 1 point
Frank sickness	Severe malaise	Moderate malaise A		Moderate malaise B	Slight malaise
(S)	(M III)	(M IIA)		(M IIB)	(M I)
≥16 points	8–15 points	5–7 points		3–4 points	1–2 points

[a] Additional qualifying symptoms.

[b] Severe or marked.

[c] Moderate.

[d] Slight.

Some related scoring methods exist. These methods score eight different symptoms with four levels of severity: 0 = none, 1 = mild, 2 = moderate, 3 = severe. Some researchers adopted these eight different symptoms as: vertigo, dizziness, bodily warmth, headache, increased salivation, stomach awareness, nausea, and dry mouth (Bonato et al., 2005; Bonato et al., 2004; Bubka and Bonato, 2003). Others adopted the eight symptoms as being: dizziness, bodily warmth, headache, sweating, stomach awareness, increased salivation, nausea, and pallor that are rated by an experimenter (Golding et al., 2009; Bijveld et al., 2008).

Another scoring system, that is widely used, is the simulator sickness questionnaire (SSQ) developed by Kennedy et al. (1993). The SSQ has 16 items of symptoms to be evaluated (see Table 4), which were selected as being more efficient items representing simulator sickness, based on the results of 1 119 pairs of data obtained with the motion sickness questionnaire (MSQ). The total SSQ score is calculated as a weighted sum of the 16 items, which are scored on a 4-point scale. The SSQ also defines three sub scores, namely:

1) “oculomotor” seeming mainly related to visual fatigue;

2) “disorientation” seeming mainly related to dizziness and vertigo; and

3) “nausea” seeming mainly related to nausea and sickness.

The SSQ has been widely used in various studies of VIMS (Lubeck et al., 2015; Ji et al., 2009; Bubka et al., 2006; Bonato et al., 2008; Diels and Howarth, 2013; Bonato et al., 2009; Diels and Howarth, 2011; Keshavarz and Hecht, 2011; Bubka et al., 2007; Kennedy et al., 2002; Duh et al., 2004; Ujike et al., 2005; Emoto et al., 2008; Lin et al., 2002; van Emmerik et al, 2011; Keshavarz et al., 2014).

Table 4 — Simulator sickness questionnaire

Symptoms	Evaluation scale			
	None	Slight	Moderate	Severe
General discomfort	+	+	+	+
Fatigue	+	+	+	+
Headache	+	+	+	+
Eye strain	+	+	+	+
Difficulty focusing	+	+	+	+
Increased salivation	+	+	+	+
Sweating	+	+	+	+
Nausea	+	+	+	+
Difficulty concentrating	+	+	+	+
Fullness of head	+	+	+	+
Blurred vision	+	+	+	+

Table 4 *(continued)*

Symptoms	Evaluation scale			
	None	Slight	Moderate	Severe
Dizzy (eyes open)	+	+	+	+
Dizzy (eyes closed)	+	+	+	+
Vertigo	+	+	+	+
Stomach awareness	+	+	+	+
Burping	+	+	+	+

The linear relationship between the SSQ total score and severity of VIMS are shown in Clause 7, where the severity of VIMS is represented by drop-out rate, the rate of people who cease to participate in the experiment of VIMS without its completion.

An alternative method of subjective scoring based on the evaluation of multiple symptoms was developed by Ohno and Ukai (2000). This evaluation method has 28 items of symptoms, which were selected from those items previously used for measuring VIMS and eye strain in the literature. Each item of the symptoms is scored on a 7-point scale. These evaluation methods have been statistically examined and accepted as evaluation methods in the literature.

There have been various physiological methods for objectively measuring VIMS. These are, for example, heart rate, heart rate variability and its related indices (e.g. LF/HF ratio), ρ−max (the maximum correlation coefficient between heart rate and blood pressure whose frequency components are limited to the Mayer waveband), respiration frequency, the electrogastrogram (EGG), skin conductance, and perspiration. Because the indices related to heart rate variability (e.g. LF/HF) can be affected by changes in the body position, it is necessary to carefully consider the validity of the values obtained.

In addition to these subjective measures and physiological recordings, other measured values, such as those related to postural sway and eye blink frequency, have been reported as being compared to other scored values.

Moreover, subjective measures not for measuring severity of sickness but for segmenting individual differences are also often used and are important for clarifying the range of participants' susceptibility in an experiment. Golding revised the motion sickness susceptibility questionnaire developed by Reason and Brand (1975) for improving the design and simplifying scoring, and also developed a short version of MSSQ (MSSQ-short) (Golding, 2006). He reported MSSQ-short provides reliability with an efficient compromise between time cost and predictability. The questionnaires in the literature are sometimes used as measure of the range of participants' susceptibility (e.g. Ji et al., 2006; van Emmerik et al., 2011; Golding et al., 2012).

Other than VIMS, vection has sometimes been measured in relation to VIMS. Several measured values of vection are often used:

1) onset latency of vection, which indicates the period between onset of the visual stimulus and that of perceived vection;

2) strength of vection (the maximum value is often attributed as the condition in which observers perceive visual stimulus as stationary while experiencing continuous self-motion); and

3) the ratio of the period in which observers experience vection to that of the stimulus period.

As an example of the strength scale of vection, Webb and Griffin (2002) used a 4-point scale (see Table 5) with which observers judge the motion of the observer and of a rotating drum (visual stimulus). Alternatively, there is another 11-point scale with 0 indicating "no motion", and with 10 indicating "perceiving self-motion that cannot be distinguished from what can be perceived during physical motion" (Ujike et al., 2004; Ujike et al., 2005).

Table 5 — An example of vection strength scale

Perception of what is moving	Meaning
Drum only	You perceive that the only thing moving is the drum (real or virtual)
Drum and self (intermittent)	You perceive the drum to be moving but also experience periods of self-motion
Drum and self (continuous)	You perceive the drum to be moving and simultaneously experience continuous self-motion
Self only	You perceive the drum to be stationary and experience continuous self-motion

6 Effective factors of visually induced motion sickness

6.1 General

Possible effective factors of VIMS are reviewed in 6.2 to 6.4, which are classified in three categories: visual image factors, visual environmental factors, and individual viewer factors. To understand these scientific reports better, the factors are described from the viewpoints of main effects, ergonomic applications and constraints. Also, the methods and results of those experiments were described.

The effects of these factors are described in studies reported in the literature, whether original paper or conference proceedings. Those studies were selected in this document with the following criteria:

1) documents reporting experiments of VIMS, not simply of traditional motion sickness, meaning that the major stimulus presented in the experiments is visual;

2) documents reporting rather detailed experimental conditions, in order to consider, for example, influential factors of the obtained results.

The descriptions of the characteristics each factor showed are sometimes based on a single report (see 6.2 to 6.4,) or are controversial even among several reports cited. Therefore, those characteristics of factors should be further investigated to be confirmed.

6.2 Effective factors: Visual image factors

6.2.1 General

The essential factor of VIMS is image motion (see 6.2.2) either real or virtual (see 6.2.3). The effective factors inherent in image motion can be the rate of motion, such as velocity (see 6.2.4, 6.2.5, 6.2.6, 6.2.8) and temporal frequency (see 6.2.7) and also the types of global image motion (see 6.2.3, 6.2.9, 6.2.11) and their combinations (see 6.2.10).

On the one hand, for the effects of the rate of motion, the VIMS can be more severe for a certain range of rotation velocity of constant rotation (see 6.2.4) or of cyclic rotation (see 6.2.6). It can also be more severe when rotation velocity is changing than when it is constant (see 6.2.5). However, for cyclic translation of global image motion, a certain temporal frequency range (with a peak at around 0,2 Hz) is reported to be larger regarding severity of VIMS (see 6.2.7).

On the other hand, for the effects of the different types of global image motion, the severity of VIMS can be larger for roll rotation than for yaw and pitch rotation (see 6.2.3), larger for off-axis rotation around the yaw axis than for on-axis rotation (see 6.2.9), or larger for forward translation than for backward translation (see 6.2.11). The combinations of rotation around different axes sometimes increases the severity of VIMS, while at other times they do not have such an effect (see 6.2.10).

Some other factors related to visual images are also reported to be effective in increasing the severity of VIMS. Those factors are spatial frequency, colour, blur of visual images and also stereoscopic presentation of images. The severity of VIMS is reported to vary depending on the spatial pattern of the rotating image (see 6.2.13); more specifically, a certain spatial frequency (0,07 cpd) of vertical stripes was more effective to induce VIMS when a rotating drum was used to present the image motion (see 6.2.12). Moreover, the severity of VIMS became larger when the moving image consisted of coloured stripes than gray or black/white stripes (see 6.2.15), or when the moving image of a checkerboard pattern was blurred than when it was not blurred (see 6.2.16). When the moving image is presented stereoscopically, the severity of VIMS represented by subjective measures often increases over non-stereoscopic presentations, but physiological recordings do not show such variations (see 6.2.18).

Moreover, some other factors of visual images are related to image content. For example, when a visual background being stationary to actual environment was presented independent from global image motion (see 6.2.14), or when cognitive orientation cues inherent in moving images are inverted (see 6.2.17), the severity of VIMS decreased.

There may be a factor of image quality in the category of visual image factors, which is sometimes considered; if the image quality of motion is higher, the severity of VIMS may be larger. However, image quality is vague and not specifically defined. Therefore, image quality is not dealt with in this document. However, image quality can be affected by luminance, contrast, image resolutions, colour depth, which is the number of bits to represent the colour of a single pixel in a bitmapped image, and other factors, which may need to be investigated.

6.2.2 Role of visual motion

6.2.2.1 Key aspect

Importance of visual image motion: visual motion is an essential factor of VIMS.

6.2.2.2 Description

For comparing the effects of moving images and still images on VIMS, two types of images were presented to observers. The first one was a moving image of a first-person view walking around VR space, and the second one was a sequence of still images, each during a period of 10 s, and which was sampled every 10 s from the above-mentioned moving image. The severity of VIMS was measured by SSQ total scores before and after the exposure (Figure 1a in Lubeck et al., 2015) and by MISC scores before, during and after the exposure (Figure 1b in Lubeck et al., 2015). They were, in some cases, significantly larger for the moving image than for the sequence of still images especially after the exposures, whereas the postural sway, which was measured before, during and after the exposure, was almost equal between the two types of images (see Figure 1c in Lubeck et al., 2015).

6.2.2.3 Applications

This factor indicates the importance of considering visual image motion to reduce VIMS; visual image motion can be produced, for example, by shooting camera motion and others.

6.2.2.4 Constraints

This factor does not necessarily indicate the possibility that moving images, consisting of a sequence of still images, do not induce motion sickness.

6.2.2.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 6.

Table 6 — Methods used in the factor: Role of visual motion

	Lubeck AJA, Bos JE, and Stins JF (2015)
Participants	15 (6 males, 9 females; age 29,5 ± 5,9)

[a] The paper describes the value as 24, which seems to be an error.

Table 6 *(continued)*

Display device	A projector and flat large screen
Display content	Motion images (12 min episodes) and still images (taken every 10 s from the motion images; presenting by changing the still images every 10 s), both taken from “Mirror’s Edge”, a first-person shooter game showing ample linear and angular motion in all dimensions.
Display resolution	(1 024 × 768) pixels, 60 Hz
Display size	(62 × 48[a])° (1,44 m × 1,08 m)
Viewing distance	1,2 m
Chin/head-rest	None
Fixation	None
Viewing period	12 min × 3 times (12 min exposure, 3 min measurements (M1), 12 min exposure, 3 min measurements (M2), 12 min exposure)
Experiment conditions	Two conditions: (a) motion images, (b) still images
Experimental design	Within subject design
Physiological measurements	Before stimulus period, M1, M2, after stimulus period: centre of foot pressure
Psychological measurements	Before/after stimulus period: SSQ Before stimulus period, M1, M2, after stimulus period: MISC

[a] The paper describes the value as 24, which seems to be an error.

6.2.3 Real and virtual motion

6.2.3.1 Key aspect

Effects of virtual motion: visual motion presented virtually is effective as well as real motion on VIMS, but the severity may be slightly less than that with real motion.

6.2.3.2 Description

For comparing the effects of real visual motion and virtual visual motion on VIMS, Webb and Griffin (2002) compared subjective scores of a 7-point motion sickness scale, obtained every 30 s (see Figure 1 in Webb and Griffin, 2002), between the condition of an optokinetic drum presenting real visual motion of yaw rotation and the condition of HMD presenting visual motion simulating virtually the yaw rotation with an optokinetic drum. The accumulated scores of the motion sickness scale are significantly smaller with the virtual motion than with the real motion. However, those scores obtained in each participant are significantly correlated between the conditions (see Figure 2c in Webb and Griffin, 2002).

6.2.3.3 Applications

This factor indicates the importance of considering visual image motion presented on electronic displays, not as real motion, to reduce VIMS.

6.2.3.4 Constraints

Although it shows the significant difference of accumulated subjective scores between the real and virtual image motion, the difference may be caused by some imperfections in the virtual presentation of images reported by the authors.

6.2.3.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 7.

Table 7 — Methods used in the factor: Role of visual motion

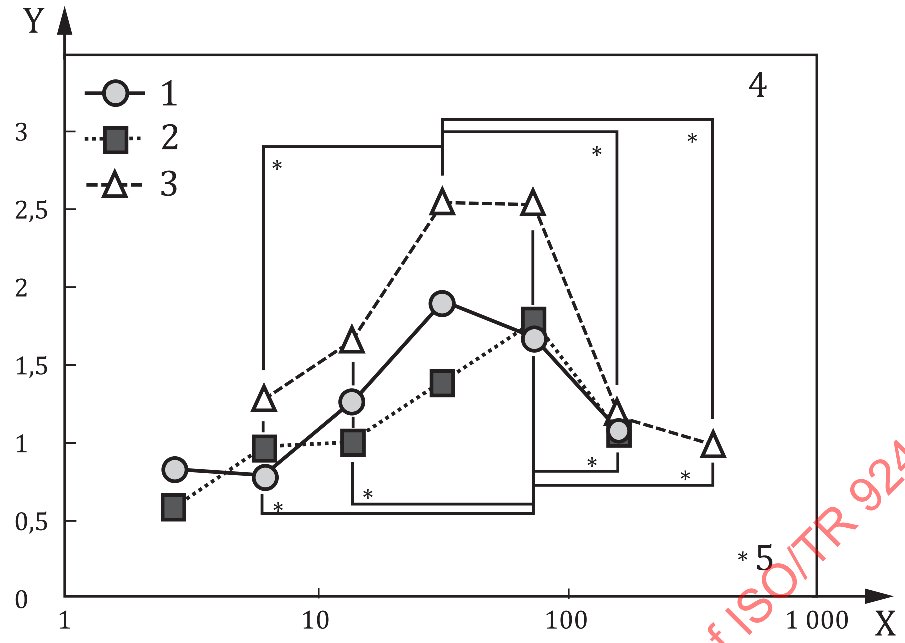
	Webb NA and Griffin MJ (2002), Exp.1	
Participants	16 (all males; age 29,5 ± 5,9)	
Display device	An optokinetic drum (diameter 100 cm, height 120 cm)	An LCD HMD (Virtual Research, VR4)
Display content	Vertical black (1,44 cd/m^2) and white (31,28 cd/m^2) stripes (75 mm wide (8°), each), rotating in 30°/s.	An animation of optokinetic drum, simulating black and white stripes (width of 8° each) rotating in 30°/s.
Display resolution	N/A; Real objects	(247 × 230) pixels, 60 Hz
Display size	(48 × 36)°, restricted by spectacles	(48 × 36)°
Viewing distance	Not specified, possibly approximately 0,5 m	Not specified, but focal point of the display was approximately 1 m
Chin/head-rest	A strap connected to the backrest of a chair restrained the head of each participant	
Fixation	None	
Viewing period	30 min for each condition	
Experiment conditions	Two conditions: (a) real optokinetic drum, (b) virtual optokinetic drum	
Experimental design	Within subject design	
Physiological measurements	None	
Psychological measurements	Before experiment: visual acuity, motion sickness history questionnaire During stimulus period: A 7-point motion sickness scale, a 4-point vection scale After stimulus period: SSQ	

6.2.4 Constant rotation of global image motion

6.2.4.1 Key aspect

Effects of velocity range of constant visual rotation: the severity of VIMS becomes the largest when the first-person view image simulates constant rotation speed of 60°/s along the yaw axis, of 30°/s along the pitch axis, and of 30 to 60°/s along the roll axis.

6.2.4.2 Description



Key

X velocity of simulated body rotation in°/s

Y sickness-related subjective score

1 pitch

2 yaw

3 roll

4 n = 39

5 $p < 0{,}05$ (Mann-Whitney test)

Figure 2 — Effects of constant rotation velocity (Ujike et al., 2004)

Using an optokinetic drum, Hu et al. (1989) presented four different speeds of visual yaw rotation to the observers. The results showed that the averaged SSMS scores were significantly different for different rotation speeds, while spectral intensities of EGG at the range of 4 to 9 cpm frequencies were significantly different among different rotation speeds (Figure 1 in Hu et al., 1989). The SSMS scores at 15°/s were significantly different from those at 60°/s and 90°/s. The spectral intensities at 15°/s were significantly different from those at 60°/s.

Using a projector and a circular wide-angle screen, Ji et al. (2009) presented a moving image of black and white stripes simulating the inside of an optokinetic drum, with the central and peripheral striped area rotating in opposite directions to each other. This differential motion was presented to reduce the incidence of vection to the observers. The results showed that both the 7-point nausea ratings ("filled circle" symbol in Figure 5 in Ji et al., 2009) and nausea severity using the free modulus magnitude estimation method ("open square" symbol in Figure 5 in Ji et al., 2009) have significant effects of rotation velocity. Both of these estimated values were significantly larger at 60°/s than their corresponding values at 0°/s. However, the values at 90°/s were not significantly different from their corresponding values at 0°/s.

Using a projector and a large flat screen, Ujike et al. (2004) presented six different rotating velocities for each of the yaw, pitch, and roll axes rotations. The results showed that the sickness-related subjective scores were significantly different among rotation velocities and marginally significant among rotation axes (Figure 3 in Ujike et al., 2004; see also Figure 2). For visual roll rotation, the peak scores are obtained at 30°/s and 70°/s, for pitch at 30°/s, and for yaw at 70°/s.

6.2.4.3 Applications

This factor is useful for considering the effects of visual rotation velocity around yaw, pitch, and roll axes in moving images, which, for example, can be produced by a shooting camera rotating as pan, tilt, or roll motion.

6.2.4.4 Constraints

The effect of this factor is shown with various sizes of visual field, and various exposure periods only for visual rotation around the yaw axis, and not around the pitch and roll axes.

6.2.4.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 8.

Table 8 — Methods used in the factor: Constant rotation of global image motion

	(i) Hu S, Stern RM, Vasey MW, and Koch KL (1989)	(ii) Ji JTT, So RHY, and Cheung RTF (2009), Exp.2	(iii) Ujike H, Yokoi T, and Saida S (2004), Exp.2
Participants	60 (29 males, 31 females; age range, 18 to 25)	16 (16 females; age range, 21 to 30)	39 (10 males, 29 females; age range, 19 to 71)
Display device	An optokinetic metallic drum (diameter 76 cm, height 91,5 cm)	A projector and circular wide-angle screen	A projector and flat large screen
Display content	24 pairs of vertical stripes with black (5,7°) and white (9,3°) covering inside the drum.	24 pairs of vertical stripes with black (5,7°) and white (9,3°) simulating the inside of a drum. Central and peripheral striped patterns rotating in opposite directions to reduce vection, but to induce Optokinetic nystagmus (OKN) by motion of central striped pattern.	Random dot patterns or a texture simulating ordinary room covering inside of a virtual rectangular solid.
Display resolution	N/A: real objects	(1 920 × 480) pixels, 60 Hz	(1 024 × 768) pixels, 60 Hz
Display size	Whole visual field	200° × 50°	82° × 67°
Viewing distance	No description (maybe below 38 cm)	No description	1 m
Chin/head-rest	Chin-rest	Chin/head-rest	None
Fixation	None	None	A fixation point at the centre of the screen
Viewing period	15 min	30 min	15 s
Experiment conditions	Four velocities of optokinetic drum: (15, 30, 60, 90)°/s	Four velocities of simulated optokinetic drum: (15, 30, 60, 90)°/s	Combinations of three visual rotation axes (yaw, pitch, roll), and seven velocities (between 0°/s to 360°/s)
Experimental design	Between subject design	Within subject design	Within subject design
Physiological measurements	During stimulus period: EGG, Respiration	During stimulus period: EOG	During stimulus period: Centre of foot pressure

Table 8 *(continued)*

Psychological measurements	Every 2 min during stimulus period: occurrence of vection symptoms of motion sickness (SSMS)	Before/after stimulus period: SSQ, Every 2 min during stimulus period: nausea severity using free modulus magnitude estimation and the 7-point nausea rating scale, vection intensity on a 4-point scale	After stimulus period: sickness related score with an eleven-point scale, vection intensity score with an eleven-point scale

6.2.5 Change of velocity of global image motion

6.2.5.1 Key aspect

Effects of velocity change during constant visual motion: the severity of VIMS becomes larger when the first-person view image simulates changing velocity of rotation (along the yaw axis) and of translation (parallel with roll axis) than constant velocity of those respective motion.

6.2.5.2 Description

Using an optokinetic drum, Bonato et al. (2005) compared three conditions: (a) the “same direction condition”: the drum rotation in the same direction was repeatedly watched for 30 s with 5 s intervals, (b) the “different direction condition”: the rotation direction alternately changed during the 5 s intervals, and (c) the “control condition”: the drum rotation was consistently watched in the same direction without 5 s intervals. The results showed that the averaged SSMS score in the different direction condition was significantly larger than the scores in the same direction condition and the control condition (Figure 1A in Bonato et al., 2005).

Using an optokinetic drum, Bubka et al. (2006) compared three conditions: (a) the “5 RPM condition”: the drum rotation with a speed of 5 rpm was repeatedly watched for 30 s with 5-s intervals, (b) the “10 RPM condition”: the rotation in the 10 rpm speed was repeatedly watched for 30 s with 5-s intervals, and (c) the “5/10 RPM condition”: the rotation speed alternately changed between 5 and 10 rpm during 5 s intervals. The ANOVA for the SSQ total scores indicated a significant effect among the three conditions ($p < 0,043$) (Figure 1A in Bubka et al., 2006). Post hoc analysis indicated that the SSQ total scores in the 5 RPM condition were significantly lower than the scores in the 5/10 RPM condition ($p < 0,05$), while the scores in the 10 RPM condition were not significantly different from the scores in the 5 RPM and 5/10 RPM conditions.

Using a CRT display, Bonato et al. (2008) compared two conditions: (a) the steady condition: the optic flow was a constant expansion, and (b) the alternating condition: the optic flow was intermittently alternated between expansion and contraction. The results showed that the SSQ total scores obtained in the steady condition were significantly lower than those obtained in the alternating condition ($p < 0,006$) (Figure 2A in Bonato et al., 2008).

6.2.5.3 Applications

This factor is useful for considering the effects of visual velocity change of rotation around yaw axis or of forward or backward motion in moving images, which, for example, can be produced by a shooting camera rotating constantly as pan, or moving constantly forward or backward with dolly motion.

6.2.5.4 Constraints

This factor does not describe the effects of velocity change of rotation around the pitch and roll axes, and of translation along the yaw and pitch axes.

6.2.5.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 9.

Table 9 — Methods used in the factor: Change of velocity of global image motion

	(i) Bonato F, Bubka A, and Story M (2005)	(ii) Bubka A, Bonato F, Urmey S, and Mycewicz D (2006)	(iii) Bonato F, Bubka A, Palmisiano S, Phillip D, and Moreno G (2008), Exp.1
Participants	12 (4 males, 8 females; age range, 20 to 44, average 24,4)	12 (7 males, 5 females; age range, 19 to 46, average 24)	14 (7 males, 7 females; age range, average 19,4)
Display device	An optokinetic drum (diameter 107 cm, height 122 cm)	An optokinetic drum (diameter 107 cm, height 122 cm)	43 cm Dell CRT monitor with Apple G5 desktop computer
Display content	12 pairs of vertical stripes (30° each) with black and white covering inside the drum.	12 pairs of vertical stripes (30° each) with black and white covering inside the drum.	The stimulus pattern consisting of an array of light blue squares against a dark background. There were 500 objects in total. The perspective was incorporated into the display.
Display resolution	N/A; real objects	N/A; real objects	(81 280 × 1 024) pixels, 85 Hz
Display size	No specific value; restricting the view with baffles to drum's interior	No specific value; restricting the view with baffles to drum's interior	53° (wide) × 45° (high) with viewing distance of 30 cm
Viewing distance	48,5 cm	48,5 cm	30 cm with monocular viewing
Chin/head-rest	Chin/head-rest	Chin/head-rest	Chin/head-rest
Fixation	None	None	None
Viewing period	16 min	4 min	5 min
Experiment conditions	(a) Same direction condition: for 30 s, rotation, for 5 s, eyes closed, for 30 s, rotation in the same direction, ... (repeating), (b) Different direction condition: for 30 s, rotation, for 5 s, eyes closed, for 30 s, rotation in the different direction, ... (repeating), (c) Control condition: the optokinetic drum was steadily rotating.	(a) 5 rpm condition: for 30 s, 5 rpm rotation, for 5 s, eyes closed, for 30 s, 5 rpm rotation in the same direction, ... (repeating), (b) 10 rpm condition: for 30 s, 10 rpm rotation, for 5 s, eyes closed, for 30 s, 10 rpm rotation in the same direction, ... (repeating), (c) 5/10 rpm condition: for 30 s, 5 rpm rotation, for 5 s, eyes closed, for 30 s, 10 rpm rotation in the same direction, ... (repeating).	(a) Steady condition: optical flow pattern viewed expanded[a] from the centre of the display monitor at a constant rate, (b) Alternating condition: optical flow pattern intermittently expanded[a] and contracted every 5 s interrupted by 1 s of stationary pattern.
Experimental design	Within subject design	Within subject design	Within subject design (Separated with 72 h)
Physiological measurements	None	None	None

[a] Rate of the expansion was consistent with an optic flow produced with a speed of 340 km/h with a visible range of 220 m.

Table 9 *(continued)*

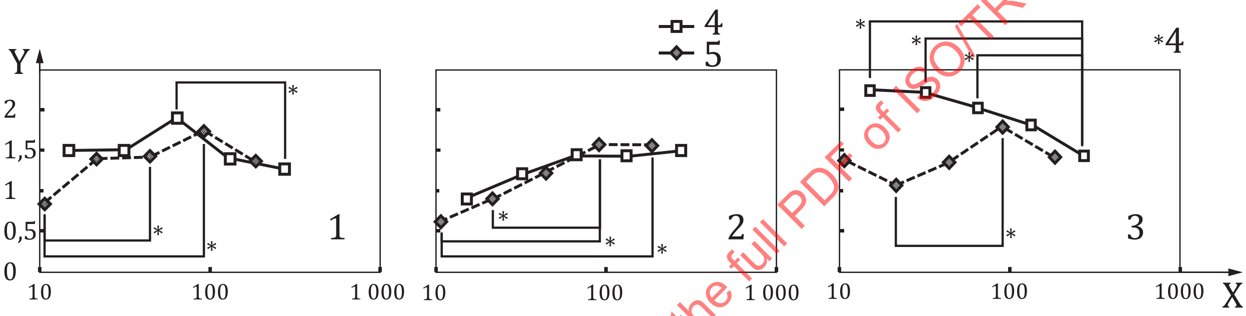
Psychological measurements	Every 2 min during stimulus period: symptoms of MS (SSMS)	Before/after stimulus period: SSQ	Before/after stimulus period: SSQ, self-motion perception
[a] Rate of the expansion was consistent with an optic flow produced with a speed of 340 km/h with a visible range of 220 m.			

6.2.6 Cyclic rotation of global image motion

6.2.6.1 Key aspect

Effects of cyclic rotation rate: the severity of VIMS becomes larger when the first-person view image simulates cyclic rotation around the yaw or pitch axes with a certain velocity range (yaw: high-pass, pitch: band-pass). For a cyclic rotation, around the roll axis, the severity of VIMS is affected by the amplitude.

6.2.6.2 Description



Key

X peak velocity of cyclic rotation in°/s
Y sickness-related subjective score
1 pitch
2 yaw
3 roll
4 amplitude of 30°
5 amplitude of 60°
6 $p < 0{,}05$ (Mann-Whitney test)

Figure 3 — Effects of oscillating (cyclical) rotation rate on sickness-related score (Ujike et al., 2005)

Effects of frequency and amplitude of oscillating rotation were investigated by Ujike et al. (2005), using a projector and a flat large screen on which either random a dot pattern or a texture simulating an ordinary room simulated an oscillating rotation around either the yaw, pitch, or roll axes. The results showed that the sickness-related subjective scores for two different amplitudes were well aligned especially for pitch and yaw axis oscillations when the data were plotted against peak velocity (Figure 3). The ranges of peak velocity for higher subjective scores depend on oscillation axis, and for roll axis, the amplitude is also an affecting factor.

6.2.6.3 Applications

This factor is useful for considering the effects of visual cyclic rotation velocity around yaw, pitch, and roll axes in moving images, which, for example, can be produced by a shooting camera rotating as pan, tilt, or roll motion.

6.2.6.4 Constraints

The dependency on peak velocity of the yaw and pitch rotation may be limited to the range of amplitude used.

6.2.6.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 10.

Table 10 — Methods used in the factor: Cyclic rotation of global image motion

	Ujike H, Kozawa R, Yokoi T, and Saida S (2005)
Participants	39 (10 males, 29 females; age range, 19 to 71)
Display device	A projector and flat large screen
Display content	Random dot patterns or a texture simulating ordinary room covering inside of a virtual rectangular solid.
Display resolution	(1 024 × 768) pixels, 60 Hz
Display size	82° × 67°
Viewing distance	1 m
Chin/head-rest	None
Fixation	A fixation point at the centre of the screen
Viewing period	60 s (5 s stationary before/after the moving stimulus)
Experiment conditions	Combinations of three visual rotation axes (yaw, pitch, roll), two different amplitudes and five different temporal frequencies (between 0,06 Hz to 1,0 Hz for amplitude of 30°, and between 0,03 Hz to 0,49 Hz for amplitude of 90°).
Experimental design	Within subject design
Physiological measurements	During stimulus period: Centre of foot pressure
Psychological measurements	After stimulus period: sickness related score with an eleven-point scale, vection intensity score with an eleven-point scale

6.2.7 Cyclic translation of global image motion

6.2.7.1 Key aspect

Effects of temporal frequency range of cyclic translation: the severity of VIMS becomes the largest when the first-person view image simulates cyclic translation back and forth (parallel with roll axis) within the frequency range of 0,2 to 0,4 Hz.

6.2.7.2 Description

The frequency response of VIMS for oscillating translation along the fore-and-aft axis was investigated by Diels and Howarth (2013), using a projector and a large flat screen on which an expanding and contracting random dot pattern was presented in two experiments. The results showed that the accumulated sickness rating (the sum of the sickness ratings over the 20 min exposure duration) increased with increasing frequency up to 0,2 Hz in Experiment 1, and these ratings decreased with increasing frequency beyond 0,2 Hz in Experiment 2 (Figure 2a in Diels and Howarth, 2013). The times to achieve sickness ratings of 2 and 3 became smaller with increasing frequency in Experiment 1. Moreover, the time to achieve the ratings of 2 was the shortest during a 0,2 Hz oscillation, while the time to achieve the ratings of 3 was the shortest during a 0,4 Hz oscillation. In these cases, those times became longer with increasing frequency (Figure 2b in Diels and Howarth, 2013). The same tendency was shown for SSQ scores (total, nausea, oculomotor, disorientation); however, there were not so much post-hoc statistical significances.

6.2.7.3 Applications

This factor is useful for considering the effects of visual cyclic translation frequency along visual axis in moving images, which, for example, can be produced by a shooting camera moving forward and backward, or probably zooming in/out.

6.2.7.4 Constraints

The results were obtained with a constant peak velocity of 34°/s; the results may be only applied to that peak velocity range of expansion/contraction motion.

6.2.7.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 11.

Table 11 — Methods used in the factor: Cyclic translation of global image motion

	Diels C and Howarth PA (2013)
Participants	Exp.1: 12 (7 males, 5 females), age 29,8 ± 5,8; Exp.2: 12 (7 males, 5 females), age 24,6 ± 2,8
Display device	A projector and flat large screen
Display content	Random dot pattern (500 white dots (10,82 cd/m^2) on a background (0,35 cd/m^2)) expanding/contracting, dot velocity and size varied exponentially as a function of their simulated location in depth.
Display resolution	(1 024 × 768) pixels, 60 Hz
Display size	93 × 78° (190 cm × 145 cm), the edges of the screen and other peripheral features occluded by goggles
Viewing distance	0,9 m
Chin/head-rest	Chin/head-rest
Fixation	A red fixation point at the centre of the screen
Viewing period	20 min
Experiment conditions	The temporal frequencies of expansion/contraction were (0,025, 0,05, 0,1, 0,2) Hz in Exp.1, and (0,2, 0,4, 0,8, 1,6) Hz in Exp.2. In the all conditions, the stimuli oscillated with a peak angular velocity of 34°/s (corresponding to 0,97 m/s)
Experimental design	Within subject design for each Exp.1 or 2
Physiological measurements	None
Psychological measurements	Before/after stimulus period: SSQ, Every 1 min during stimulus period: standard sickness rating in 4-point scale, After stimulus period: perceiving vection or not

6.2.8 Velocity effects of forward motion with complicated motion

6.2.8.1 Key aspect

Effects of navigation velocity: when the first-person view image simulates moving passively forward along a road, the severity of VIMS depends on velocity ranges of moving forward (navigation speeds). For a smaller range of (3 to 10) m/s used in the reported experiment, the nausea rating basically increases with navigation speeds, whereas for a larger range beyond 10 m/s, the severity is almost constant, irrespective of navigation speeds.

6.2.8.2 Description

For investigating the effects of navigation speed on the severity of VIMS using the VR type of HMD presentation, So et al. (2001) presented virtual images of going along a predetermined trajectory in a virtual city scene for 30 min with eight different navigation speeds. The results of nausea ratings every 5 min showed that the duration has significant effects on nausea ratings, and the nausea rating significantly increased with duration after 10 min (Figure 3 in So et al., 2001). The nausea ratings were also reported to be divided into two regions in terms of navigation speeds: (a) 3 m/s to 10 m/s, where nausea ratings increased with navigation speeds, and (b) beyond 10 m/s, where nausea ratings remain almost constant. Actually, it was statistically (Student-Newman-Keuls groupings) indicated that nausea ratings peaked at a speed of 10 m/s and became steady at higher speeds.

6.2.8.3 Applications

This factor is useful for considering the effects of navigation speed in moving images, which, for example, can be produced by a shooting camera moving forward by dolly motion, or by being mounted on a moving vehicle.

6.2.8.4 Constraints

Although the effect of specific navigation speed on nausea ratings (score increasing from 3 m/s to 10 m/s, and stabilized after 10 m/s) may depend on image content (here, they used virtual image of city scene), the general characteristics (score increasing with speed and saturating at certain speed) may be generally applicable.

6.2.8.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 12.

Table 12 — Methods used in the factor — Velocity effects of forward motion

	So RHY, Lo WT, and Ho ATK (2001)
Participants	96[a] (96 males, 0 females), age range 19 to 38
Display device	An LCD HMD (VR4, of Virtual Research Systems, Inc.)
Display content	A virtual city with trees, railway tracks, overhead cables, trains, a train station, and skyscrapers can be seen in binocular mode during virtually moving along a predetermined path, and participants could steer their viewpoint using head movements (head position and orientation were measured at a rate of 30/s; attention paid to ensure that the system response lags were similar across all eight navigation speed conditions).
Display resolution	(247 × 230) pixels, 60 Hz
Display size	48° × 36°
Viewing distance	N/A
Chin/head-rest	None
Fixation	None
Viewing period	30 min
Experiment conditions	Eight navigation speeds[b] of (3,3; 4,3; 5,9; 7,9; 9,5; 23,6; 29,6; and 59,2) m/s root mean square (They were asked, once every 30 s, to turn their heads horizontally to one side (covering 45° in about 1 s)).
Experimental design	Between subject design (12 participants participated in one of the eight speed conditions)
Physiological measurements	None
Psychological measurements	Before/after stimulus period: SSQ, Every 5 min during stimulus period: The seven-point nausea scale, After stimulus period: Vection sensation on a 4-point scale

[a] 10 participants terminated the experiment because reaching nausea score of 6 during stimulus period.

[b] Average velocities (RMS) along six axes at each navigation speed are shown in Table 1 in So, Lo and Ho (2001).

6.2.9 Off-axis rotation of visual yaw rotation

6.2.9.1 Key aspect

Effects of off-axis rotation around yaw axis: the severity of VIMS becomes larger when the first-person view image simulates yaw rotation tilted from 0° to 10° and becomes the largest when the tilted angle is in the range between 18° to 54°. The severity of VIMS, in this case, becomes the largest when the velocity of rotation is 72°/s, which produces oscillation of 0,2 Hz. However, the severity may be smaller than the real off-axis rotation.

6.2.9.2 Description

Bubka and Bonato (2003) compared three different tilt levels of an optokinetic drum (0°, 5°, 10°) during a constant rotation speed. The results showed that time to reach the midpoint (11) of the SSMS scale was significantly longer in the 0° tilt condition than in the 5° and 10° tilt conditions. The tendency of converging curves in the three condition at around 8 min in the graph in Figure 3 in Bubka and Bonato (2003) is possibly caused by different drop-out rates in the conditions; the author reported that the data at 10 min and longer periods were not plotted because plotting those data is not informative.

Golding et al. (2009) compared different tilt angles and different wobbling frequencies of visual OVAR and also different tilt angles of real OVAR in four different experiments. The results showed that the total symptom score at 18°, 36°, 54°, and 72° have a significant angle effect, and the total symptom score at 54° is significantly larger than that at 72° (in their exp.3, shown in Figure 2 in Golding et al., 2009, consisting the results in exp2 to 4). However, the authors argued for the real OVAR possibly to "have failed to modulate nauseogenicity because of overriding somatosensory cues to the Earth vertical".

Bijveld et al. (2008) compared real off-vertical axis rotation (OVAR) in darkness (condition A: dark OVAR) with real OVAR with eyes open in brightness (condition B: light OVAR) and while watching a video image of visual motion experienced in condition B in a seated upright position (condition C: video). The results showed that visual motion alone (condition C) was less nauseogenic than real OVAR conditions (A and B) (Figure 2 in Bijveld et al., 2008); time to reach all sickness rating levels (2, 3, or 4) was significantly shorter for real OVAR conditions (A and B) than for the video condition (C).

6.2.9.3 Applications

This factor is useful for considering the effects of visually off-axis rotation and its velocity in moving images, which, for example, can be produced by a shooting camera held on the shoulder rotating around yaw axis.

6.2.9.4 Constraints

The effect of this factor is described for some limited conditions and is not clear when the factor of visual field size is changed.

6.2.9.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 13.

Table 13 — Methods used in the factor: Off-axis rotation of visual yaw motion

	(i) Bubka A and Bonato F (2003)	(ii) Golding JF, Arun S, Wortley E, Wotton-Hamrioui K, Cousins S, and Gresty M (2009)	(iii) Bijveld MMC, Bronstein AM, Golding JF, and Gresty M (2008)
Participants	12 graduate students	Exp1: 14 (3 males, 11 females; age range, 20 to 26, 20,9 ± 1,7; MSSQ: 30,8 ± 20,3 %) Exp2: 12 (2 males, 10 females; age range, 18 to 26, 21,7 ± 1,8; MSSQ: 72,1 ± 30,7%) Exp3: 24 (9 males, 15 females; age range, 19 to 28, 22,3 ± 1,9; MSSQ: 81,9 ± 15,0 %) Exp4: 12 (3 males, 9 females; age range, 18 to 33, 23,8 ± 4,6; MSSQ: 92,7 ± 7,7 %)	12 (5 males, 7 females; age range, 22 to 61, 31,6 ± 13,3; MSSQ: percentile score 66 ± 30,9 %)
Display device	An optokinetic drum (diameter 107 cm, height 122 cm)	A projector and flat large screen (2 m × 2 m, 1024 pixels × 768 pixels, 60 Hz)	In the conditions A and B: a motorized chair In the condition C: a projector and flat large screen
Display content	24 pairs of vertical stripes with black and white (width of 7,5°, each) covering inside the drum. Drum was set completely perpendicular to the horizontal plane (0° condition), or could be tilted up to 10°. Rotation speed was 60°/s.	360° photograph of a coastline as might be seen from an aircraft.	In the condition A: eye closed In the condition B: a room (3 × 3,15) m at which centre the chair was located (30 s-ramp to 72°/s which was held for 30 s). In the condition C: videoed image from the chair in the condition B, but starting from tilted rotation
Display resolution	N/A; real objects	(1 024 × 768) pixels, 60 Hz	N/A; real objects in the conditions A and B (1 024 × 768) pixels, 60 Hz in the condition C
Display size	No specific value; restricting the view with baffles to drum's interior	84°, w/ circular perimeter, restricted by facemask mounted with a cone	Whole visual field in the condition B 84° view (2 × 2 @1,12 m (84° × 84°)) restricted by goggles in the condition C
Viewing distance	Not specified (possibly 53,5 cm)	1,12 m	Approximately 1,5 m in the conditions A and B 1,12 m in the condition C

[a] Three conditions were conducted on three separate days, each separated in 48 h to 72 h.

[b] Experimental conditions in each experiment were separated in15 min washout period.

[c] Experimental conditions were separated in five days.

[d] No overlap of observers across experiments.

Table 13 *(continued)*

Chin/head-rest	Chin/head-rest	None	Head-rest on the chair
Fixation	None	None	None
Viewing period	16 min	10 min	20 min
Experiment conditions	Three tilt conditions[a] of optokinetic drum: 0°, 5°, and 10°	Conditions[b] provided in each experiment: Exp1 Tilt of axis: 18° Frequency: (0,05, 0,20, and 0,80) Hz Exp2 Tilt of axis: 0°, 45°, 90° Frequency: 0,2 Hz Exp3 Tilt of axis: 18°, 36°, 54°, 72° Frequency: 0,2 Hz Exp4 Tilt of Observers: 0°, 45° and 90° roll tilt	Three conditions[c]: A: rotated in off-vertical axis rotation (OVAR) in total darkness B: rotated in OVAR with eyes open in the light C: viewing video in the condition B
Experimental design	Within subject design	Within subject design for each experiment[d]	Within subject design
Physiological measurements	None	None	None
Psychological measurements	Every 2 min during stimulus period: Well-being in 10-point scale, symptoms of MS (SSMS)	Every 1 min during stimulus period: Sickness rating scale 1, 2, 3, 4, 5, and 10 min after stimulus period: Sickness rating scale Before/after stimulus period: Symptoms of MS	Every 1 min during stimulus period: Sickness rating scale, symptoms of MS After stimulus period: Occurrence of vection (in the condition C) 0, 1, 2, 3, 4, 5, 10, 15, and 20 min after stimulus period: Sickness rating scale

[a] Three conditions were conducted on three separate days, each separated in 48 h to 72 h.

[b] Experimental conditions in each experiment were separated in15 min washout period.

[c] Experimental conditions were separated in five days.

[d] No overlap of observers across experiments.

6.2.10 Combination of different axes of visual motion

6.2.10.1 Key aspect

Effects of combination of different axes of visual motion: when the visual motion around/along different axes are combined, the severity of VIMS basically becomes larger, but sometimes does not.

6.2.10.2 Description

Using an optokinetic drum, Andre et al. (1996) presented the observers two different global image motion: one was yaw rotation produced with vertical stripes covering the inside of the drum, and the other was also yaw rotation, but with tilted stripes. The vertical stripes produced simple yaw rotation, while the tilted stripes produced a combination of yaw rotation and vertical translation. The results showed that gastric tachyarrhythmic activity as an index of VIMS was significantly higher for subjects in the tilted stripe condition than in the vertical stripe condition during the rotation period but not during the recovery period (Table 1 in Andre et al., 1996). However, there were no significant differences between SSMS scores in those conditions.

Two different global image motions, single-axis pitch rotation and the combination of dual-axis pitch and roll rotations, were presented with HMD by Bonato et al. (2009). The results showed that SSQ total scores and sub-scores of nausea, oculomotor, and disorientation were significantly larger in the dual-axis condition (Figure 2 in Bonato et al., 2009).

Using a projector and a large flat screen, Diels and Howarth (2011) presented their observers three different types of global image motion: (i) oscillating roll motion, (ii) linear motion in the fore-and-aft axis, and (iii) spiral motion, which is the combination of those two different motions. Although the combination of the two different motions was supposed to increase the level of VIMS, the results did not show such combination effects; the accumulated sickness rating in the combined condition was slightly, but insignificantly, lower than in the oscillating roll and linear motion in the fore-and-aft axis (Figure 2 in Diels and Howarth, 2011). Moreover, SSQ total scores and sub-scores were not significantly different between the three conditions.

Kesharvarz et al. (2011), using simulated images from the front view of rollercoaster rides, presented global image motion including translational movement in the fore-aft axis and additional rotational motion either in pitch only, around the pitch and roll axes, or in the pitch, roll, and yaw axes. The results showed that although the lowest scores of accumulated FMS scale were obtained for the pitch-only condition, there was no significant difference in the scores between the pitch/roll and pitch/roll/yaw conditions (Figure 2 in Keshavarz and Hecht, 2011). The same tendency for SSQ scores was also obtained.

6.2.10.3 Applications

This factor is useful for considering the effects of combinations of different types of visual motion in moving images, which, for example, can be produced by a shooting camera moving with being mounted on a moving vehicle.

6.2.10.4 Constraints

The combinations investigated are limited, and also the conditions of combined motion are limited, and the effect of this factor is not clear when the factor of visual field size is changed.

6.2.10.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 14.

Table 14 — Methods used in the factor: Combination of different axes of visual motion

	(i) Andre JT, Muth ER, Stern RM, and Leibowitz HW (1996)	(ii) Bonato F, Bubka A, and Palmisano S (2009)	(iii) Diels C and Howarth PA (2011)	(iv) Keshavarz B and Hecht H (2011)
Participants	60 (29 males, 31 females; age range, 18 to 25)	19 (5 males, 12 females; age range, 18 to 22, average 19,8)	12 (7 males, 5 females; age range, 26.08 ± 6,13)	61 (14 males, 47 females; age range, 24,4 ± 6,8[a])
Display device	An optokinetic metallic drum (diameter 76 cm, height 91,5 cm)	An LC HMD (IPD = 6 cm)	A projector and flat large screen	A projector and flat large screen

[a] Age range was calculated from values reported separately for each of the conditions.

[b] Equal nauseogenicity of R and FB conditions were identified in a pilot study.

Table 14 *(continued)*

Display content	Stripes of black (1,35 or 1,17 cd/m^2) and white (27,39 or 28,40 cd/m^2) covering inside the drum, either vertically or tilted 15° to the direction of rotation.	A virtual 5 m cubic room containing a black and white checkerboard pattern on each wall, which was viewed through a vertical scaffold.	Random dot pattern (500 white dots (10,82 cd/m^2) on a background (0,35 cd/m^2)) either rotating along roll axis or expanding/contracting, or combination of both.	CG images simulating view from rollercoaster, of which motion includes either (a) pitch only, (b) pitch and roll, or (c) pitch, roll and yaw.
Display resolution	N/A; Real objects	(1 280 × 1 024) pixels, 60 Hz	(1 024 × 768) pixels, 60 Hz	(1 024 × 768) pixels
Display size	Whole visual field	47° × 38°	65° × 59° (190 × 145 cm), the edges of the screen and other peripheral features occluded by goggles	62° × 48° (164 × 123 cm)
Viewing distance	No description	No description	0,8 m	1,35 m
Chin/head-rest	Chin/head-rest	None	Chin/head-rest	Chin-rest
Fixation	None	None	A fixation point at the centre of the screen	None
Viewing period	16 min (stationary before/after the moving stimulus)	5 min	20 min	(a) 14 min 48 s, (b) 14 min 58 s, (c) 14 min 39 s.
Experiment conditions	Two conditions: (a) vertical stripes, (b) tilted stripes.	Two conditions: (a) single-axis rotation condition in which the virtual room rotated along pitch axis, (b) dual-axes rotation condition in which the virtual room rotated along both pitch and roll axes.	Three conditions: (a) R[b]: oscillating roll motion (2 Hz, Amp. 60°, ave. angular vel. 48°/s), (b) B[b]: expand/contract-ing (2 Hz, peak vel. 34°/s), dot size: 0,12° to 4,53°, (c) RFB: combination of R and FB.	Three conditions: (a) pitch: cumulative pitch 826°, forward 24 kph to 116 kph, 19 runs, (b) pitch/roll: cumulative pitch 826° and roll 2 070°, forward 24 kph to 114 kph, 18 runs, (c) pitch/roll/yaw: cumulative pitch 1 095°, roll 2 160° and yaw 1 798°, forward 24 kph to 114 kph, 18 runs.
Experimental design	Between subject design	Within subject design	Within subject design	Between subject design
Physiological measurements	During stimulus period: EGG, respiration	None	None	None

[a] Age range was calculated from values reported separately for each of the conditions.

[b] Equal nauseogenicity of R and FB conditions were identified in a pilot study.

Table 14 *(continued)*

Psychological measurements	Every 3 min during stimulus period: Symptoms of MS (SSMS)	Before/after stimulus period: SSQ, After finishing the experiment: Comparing the two conditions and indicating which one made them feel sicker	Before/after stimulus period: SSQ, Every 1 min during stimulus period: Standard sickness rating in 4-point scale, During stimulus period: Pressing button during perceiving vection, After stimulus period: Vection intensity score with seven-point scale	Before/after experiment and 5 h later: SSQ, Every 1 min during stimulus period: FMS scale, Every 1 h after experiment: FMS scale, After experiment: How frequently experience vection and presence in 4-point scale

[a] Age range was calculated from values reported separately for each of the conditions.

[b] Equal nauseogenicity of R and FB conditions were identified in a pilot study.

6.2.11 Anisotropy effects of back and forth translation

6.2.11.1 Key aspect

Anisotropy effects of back and forth translation: the severity of VIMS becomes larger when the first-person view image simulates forward translation (parallel with roll axis) than backward translation.

6.2.11.2 Description

Global image motion of either expansion or contraction was presented in an expansion condition and a contraction condition, both for 5 min using an array of 500 light blue squares on a dark background, presented on a CRT display (Bubka et al., 2007). The results showed that SSQ total scores and nausea and oculomotor sub-scores obtained in the expansion condition are significantly larger than those obtained in the contraction condition (Table 1 in Bubka et al., 2007).

6.2.11.3 Applications

This factor is useful for considering the directional effects of visually moving forward and backward in moving images, which, for example, can be produced by a shooting camera moving with dolly action.

6.2.11.4 Constraints

The effect of this factor is not clear when the factor of visual field size is changed.

6.2.11.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 15.

Table 15 — Methods used in the factor: Anisotropy effects of back and forth translation

	Bubka A, Bonato F, and Palmisano S (2007)
Participants	16 (6 males, 10 females; age range 21 to 46, average 24,4)
Display device	43 cm Dell CRT monitor with Apple G5 desktop computer

[a] Rate of the expansion was consistent with an optic flow produced with a speed of 340 km/h with a visible range of 220 m.

[b] The participation scheduled for a subsequent condition in one week.

Table 15 *(continued)*

Display content	The stimulus pattern consisted of an array of light blue squares against a dark background; there were 500 objects in total; perspective was incorporated into the display. Each element subtended 1,3° at maximum size.
Display resolution	(1 280 × 1 024) pixels, 85 Hz
Display size	53° (wide) × 45° (high) with viewing distance of 30 cm
Viewing distance	30 cm with monocular viewing
Chin/head-rest	Chin/head-rest
Fixation	None
Viewing period	5 min
Experiment conditions	(a) Expanding[a] condition: the array of squares steadily expanded from the centre of the screen, (b) Contracting condition: the array of squares steadily contracted.
Experimental design	Within subject design[b]
Physiological measurements	None
Psychological measurements	Before/after stimulus period: SSQ, After stimulus period: Self-motion perception

[a] Rate of the expansion was consistent with an optic flow produced with a speed of 340 km/h with a visible range of 220 m.

[b] The participation scheduled for a subsequent condition in one week.

6.2.12 Spatial frequency of visual image

6.2.12.1 Key aspect

Effects of spatial frequency of rotating image pattern: the severity of VIMS becomes the largest when the first-person view image simulates constant rotation along the yaw axis with visual pattern of stripes having a certain spatial frequency range (approx. 0,07 cpd).

6.2.12.2 Description

Global image motion of yaw rotation, for 16 min using an optokinetic drum, of which the inner surface was covered by different pairs of black and white stripes: 6, 12, 24, 48, and 96 pairs, was presented in Hu et al. (1997). They reported that the participants in the group of 24-pairs stripes showed significantly larger averaged SSMS scores (Figure 2 in Hu et al., 1997) than the participants in the groups of 6-, 12-, 48- and 96-pairs stripes, and significantly larger ratios of EGG 4-9 cpm spectral intensity (Figure 3 in Hu et al., 1997) than the participants in the groups of 6-, 12- and 96-pairs stripes.

6.2.12.3 Applications

This factor is useful for considering the effects of visual image pattern of a background in moving images, which, for example, can be produced by a shooting camera constantly rotating as pan motion.

6.2.12.4 Constraints

The investigated conditions are limited to yaw motion and to striped pattern of images. Therefore, it is not clear whether the effect of spatial frequency is also applicable to the spatial frequency components of natural images. Moreover, the effect of this factor is not clear when the factor of visual field size is changed.

6.2.12.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 16.

Table 16 — Methods used in the factor: Spatial frequency of visual image

	Hu S, Davis MS, Klose AH, Zabinsky EM, Meux SP, Jacobsen HA, Westfall JM, and Gruber MB (1997) Exp.2
Participants	100 (age range, 18 to 25)
Display device	A metal cylinder (diameter 50 cm, height 70 cm)
Display content	Alternated black and white stripes covered the inner surface of the drum; width of each stripe was (13,09, 6,55, 3,27, 1,64, 0,82) cm (black and white has equal width). Rotating velocity was 60°/s (or 10 rpm).
Display resolution	N/A; real objects
Display size	Whole visual field
Viewing distance	No description
Chin/head-rest	None (participants' head and body were not restrained)
Fixation	None
Viewing period	16 min (8 min baseline before the viewing period)
Experiment conditions	Five different frequencies of stripes: 6 (13,09 cm), 12 (6,55 cm), 24 (3,27 cm), 48 (1,64 cm), 96 (0,82 cm)
Experimental design	Between subject design
Physiological measurements	During stimulus period: EOG, EGG (spectral analysis for each 4 min)
Psychological measurements	Every 2 min during stimulus period: Vection assessment scaling from 0 to 10, symptoms of MS (SSMS)

6.2.13 Spatial pattern of visual image

6.2.13.1 Key aspect

Effects of spatial pattern of rotating image: the severity of VIMS can be varied depending on spatial pattern of rotating image around yaw axis, even when velocity of vection is perceived equally.

6.2.13.2 Description

Global image motion was presented in Kennedy et al. (2002) using an optokinetic drum, of which the inner surface was covered by either one of four different textures: wood, speckle, waves or clouds. They found lower SSQ scores for the wood pattern than for the other three patterns (Figure 9 in Kennedy et al., 2010); although not significant, they reported that these results were obtained consistently with a pilot study. Irrespective of the difference in SSQ scores, the estimated velocity was not very different among the four different patterns (Figure 7 in Kennedy et al., 2010).

6.2.13.3 Applications

This factor is useful for considering the effects of visual image pattern of a background in moving images, which, for example, can be produced by a shooting camera rotating constantly as pan motion.

6.2.13.4 Constraints

The investigated conditions are limited to yaw motion. Moreover, the effect of this factor is not clear when the factor of visual field size is changed.

6.2.13.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 17.

Table 17 — Methods used in the factor: Spatial pattern of visual image

	Kennedy RS, Stanney KM, Rolland J, Ordy MJ, and Mead AP (2002)
Participants	36 (18 males, 18 females; age range, 17 to 64, 25,7 ± 11,2)
Display device	An optokinetic drum
Display content	Four different patterns of the inside of the optokinetic drum: (a) wood, (b) dots, (c) waves, and (d) clouds. Rotation speed was from 10°/s to 160°/s, every 10°/s.
Display resolution	N/A; real objects
Display size	No specific value
Viewing distance	No description
Chin/head-rest	No description
Fixation	None
Viewing period	No description
Experiment conditions	Four different patterns of the inside of the optokinetic drum as the conditions: (a) wood, (b) dots, (c) waves, and (d) clouds.
Experimental design	Within subject design
Physiological measurements	None
Psychological measurements	Perceived velocity of vection, etc. SSQ

6.2.14 Independent visual background from visual motion

6.2.14.1 Key aspect

Effects of independent visual background from global image motion: the severity of VIMS can be reduced when visual background indicating horizontal and vertical direction exists independent of global image motion.

6.2.14.2 Description

A driving simulator was used to present global image motion with four combinations of two “independent visual background” (IVB) conditions (IVB or non-IVB) and two “stereoscopic” conditions (stereo or non-stereo) in Duh et al. (2004). IVB was fixed with respect to gravity in the “sky” area behind and above “mountains” in the virtual image presented on a screen. They found that SSQ scores in the IVB condition are significantly less than those in the non-IVB condition (Figure 6a in Duh et al., 2004), indicating that the presence of IVB reduces the severity of VIMS.

6.2.14.3 Applications

This factor is useful for considering reducing VIMS from moving images, while, for example, producing moving images.

6.2.14.4 Constraints

The investigated conditions are limited to specific image pattern of a background and its size in visual field. Moreover, this factor is not investigated regarding the effect of duration of exposure.

6.2.14.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 18.

Table 18 — Methods used in the factor — Independent visual background from visual motion

	Duh HB-L, Paker DE, and Furness TA (2004), Exp.2
Participants	11 (4 males, 7 females; age range, 18 to 32)
Display device	A driving simulator (a real Saturn car (Ford Motor Company) and three wall screens) CrystalEyes shutter glasses
Display content	Crayolaland (EVL, Univ. of Illinois), a cartoon world including a cabin, pond, flower bed and forest, generated by Cave software library. Independent visual background (IVB) was fixed with respect to gravity was presented in the “sky” behind and above the mountains of Crayolaland. IVB was as white grid (spatial frequency of 5 cycles per radian); the grid IVB vertical lines were aligned with gravity.
Display resolution	No description
Display size	No description
Viewing distance	No description[a]
Chin/head-rest	No description
Fixation	None
Viewing period	2 min
Experiment conditions	Four visual conditions, combinations of (a) two levels of IVB conditions (present, absent), and (b) two levels of stereo conditions (no, yes)
Experimental design	Within subject design
Physiological measurements	None
Psychological measurements	SSQ, E2i Questionnaire, to evaluate the “sense of presence” and “enjoyment”

[a] The participants sat in the car and observed the stimulus on the screens.

6.2.15 Chromaticity of visual image

6.2.15.1 Key aspect

Effects of chromaticity: the severity of VIMS becomes larger when the first-person view image simulates constant rotation along the yaw axis with visual pattern of coloured stripes, compared to when simulating with gray stripes (even with the same luminance pattern as the coloured pattern) or simply black and white.

6.2.15.2 Description

Global image motion was presented using an optokinetic drum of which the inner surface was textured with vertical stripes. Bonato et al. (2004) compared the score of SSMS (Figure 2B in Bonato et al., 2004) and the time to midpoint of SSMS (Figure 2A in Bonato et al., 2004). They found that the average time for reaching the midpoint (11) of the SSMS scale was significantly different among the conditions, while the averaged value obtained in the “chromatic” condition was significantly lower than those in the “black and white” and “gray shade” conditions.

6.2.15.3 Applications

This factor is useful for considering the effects of visual image colour of a background in moving images, which, for example, can be produced by a shooting camera rotating constantly as pan motion.

6.2.15.4 Constraints

The investigated conditions are limited to specific colour pattern of background, simple stripes, and its size in visual field.

6.2.15.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 19.

Table 19 — Methods used in the factor: Chromaticity of visual image

	Bonato F, Bubka A, and Alfieri L (2004)
Participants	12 (4 males, 8 females; age range, 20 to 43, average 25)
Display device	An optokinetic drum (diameter 107 cm, height 122 cm)
Display content	12 vertical stripes (3° each) covering the inside of the drum. The stripes were either black/white, gray shades, or chromatic (the details are shown in experimental conditions). The rotation speed was 30°/s (5 rpm).
Display resolution	N/A; real objects
Display size	No specific value; restricting the view with baffles to drum's interior
Viewing distance	53,5 cm
Chin/head-rest	Chin/head-rest
Fixation	None
Viewing period	16 min or until well-being score reaching "5" or higher
Experiment conditions	Three stripe conditions[a] of optokinetic drum: (a) Black and white: the stripes were simply alternated with black (36,0 cd/m^2) and white (1,6 cd/m^2), (b) Gray shade[b]: in addition to black and white, there were four different shades (6,6, 10,5, 11,9, 24,6 cd/m^2), (c) Chromatic[b]: in addition to black and white, there were four different colours (red, blue, green, yellow), each of which luminance was 6,7, 10,6, 11,8, 25,0 cd/m^2.
Experimental design	Within subject design
Physiological measurements	None
Psychological measurements	Every 2 min during stimulus period: Wellbeing in 10-point scale, symptoms of MS (SSMS)

[a] All three conditions have black and white, then global contrast was held constant across conditions. Conducted on three separate days, each separated in 48 h to 72 h.

[b] Gray shade and chromatic conditions have almost the same combination of luminance.

6.2.16 Blur of visual image

6.2.16.1 Key aspect

Effects of inverted orientation of visual images: the severity of VIMS becomes larger when visual images are blurred.

6.2.16.2 Description

When the visual motion image presented by rotating drum was blurred by a frosted filter attached to a pair of goggles, sickness scores obtained as SSQ total score, and sub-scores for oculomotor and disorientation, significantly increased relative to the condition in which the visual motion image was not blurred (Figure 2 in Bonato et al., 2015).

6.2.16.3 Applications

This factor is useful for considering the effects of blurred visual image on VIMS.

6.2.16.4 Constraints

The investigated conditions are limited to a black and white checker pattern without cognitive orientation cues, and also limited to yaw rotation. Moreover, this factor is not investigated as regards the effect of visual field size.

The effect of factor may be explained by spatial frequency characteristics, which is described in 6.2.12. However, the spatial frequency component resulted with blurring of visual image in the cited study are not clear. Therefore, the comparison of those results in 6.2.16.2 and those in 6.2.12.2 is difficult.

6.2.16.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 20.

Table 20 — Methods used in the factor — Blur of visual image

	Bonato F, Bubka A, and Thornton W (2015)
Participants	15 (10 females, 5 males; age range, 18 to 49, average 24,9)
Display device	An optokinetic drum (diameter 107 cm, height 122 cm)
Display content	A black and a white checkerboard pattern covering the inside of the drum. The size of each patch: (30 × 9)° (width × height). The rotation speed was 60°/s (10 rpm).
Display resolution	N/A; real objects except a frosted filter was used in the “blurred” condition
Display size	No specific value; restricting the view with baffles to drum’s interior
Viewing distance	48,5 cm
Chin/head-rest	Chin/head-rest
Fixation	None
Viewing period	10 min
Experiment conditions	Two visual conditions[a]: (a) Blur: the visual stimulus was seen as blurred, because a frosted acetate filter was adhered to the surface of a transparent plastic front of a pair of goggles, (b) Control: the visual stimulus was seen as clear, because a transparent plastic front of a pair of goggles was left clear and unobstructed.
Experimental design	Within subject design
Physiological measurements	None
Psychological measurements	Before/after each stimulus period: SSQ, After each stimulus period: overall sickness rating in an 11-point scale (0 to 10), vection rating in an 11-point scale (0 to 10)

[a] The two conditions were conducted on two separate days, each separated 48 h to 72 h.

6.2.17 Cognitive orientation cues of visual image

6.2.17.1 Key aspect

Effects of inverted orientation of visual images: the severity of VIMS becomes smaller when the cognitive orientation cues of visual images are varied, such as inverted.

6.2.17.2 Description

Panoramic scene from Westminster Bridge over the river Thames was presented by Golding et al. (2012) as an off-vertical (18° tilted from vertical) axis rotation image for 10 min. In one condition, the image was set at upright position while in the other condition, it was set at inverted position. The sickness rating score with six-point scale showed that upright scene was significantly more nauseogenic than the inverted scene (Figure 1 in Golding et al., 2012).

6.2.17.3 Applications

This factor is useful for considering the effects of visual image orientation on VIMS, especially when cognitive orientation of images is varied to a great extent, such as inverted position.

6.2.17.4 Constraints

The investigated conditions are limited to off-vertical axis rotation. Moreover, in the same reference, the author showed, in the pilot study, that the reducing effects of inverted images cannot be shown, possibly when the inverted view did not look much different from the upright view.

6.2.17.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 21.

Table 21 — Methods used in the factor — Cognitive orientation cues of visual image

	Golding JF, Doolan K, Acharya A, Tribak M, and Gresty MA (2012): Main experiment
Participants	22 (10 females, 12 males; age average 35,2 ± 15,2; MSSQ: percentile score 57,8 ± 30,1 %)
Display device	A projector and a screen (2 m × 2 m)
Display content	A 360° panorama as seen from Westminster Bridge over the river Thames. The seen includes universally familiar and containing numerous unambiguous verticality cues, such as Big Ben, Parliament, the London Eye, the river, pedestrians, cars, pavement road signs, buildings, and a highly contrasted sky. The seen rotated about an axis tilted 18° tilt from the vertical at 72°/s (12 rpm; 0,2 Hz).
Display resolution	(1 024 × 768) pixels
Display size	2 m × 2 m; restricting the field of view to 84° to exclude peripheral vision of the laboratory
Viewing distance	112 cm
Chin/head-rest	No description
Fixation	None
Viewing period	16 min or until sickness rating score reaching “4”
Experiment conditions	Two conditions[a] of image orientation: (a) Upright: the tilted rotating stimulus image was in upright position, (b) Inverted: the tilted rotating stimulus image was in inverted position.
Experimental design	Within subject design
Physiological measurements	None
Psychological measurements	Every 1 min during stimulus period, and at (1, 2, 3, 4, 5, 10 and 15) min after the end of stimulus presentation: sickness rating in 6-point scale (SR scale), Before/After stimulus period: SSQ, After stimulus period: percentage of time that they experienced vection and its characteristics (constancy/fluctuations)

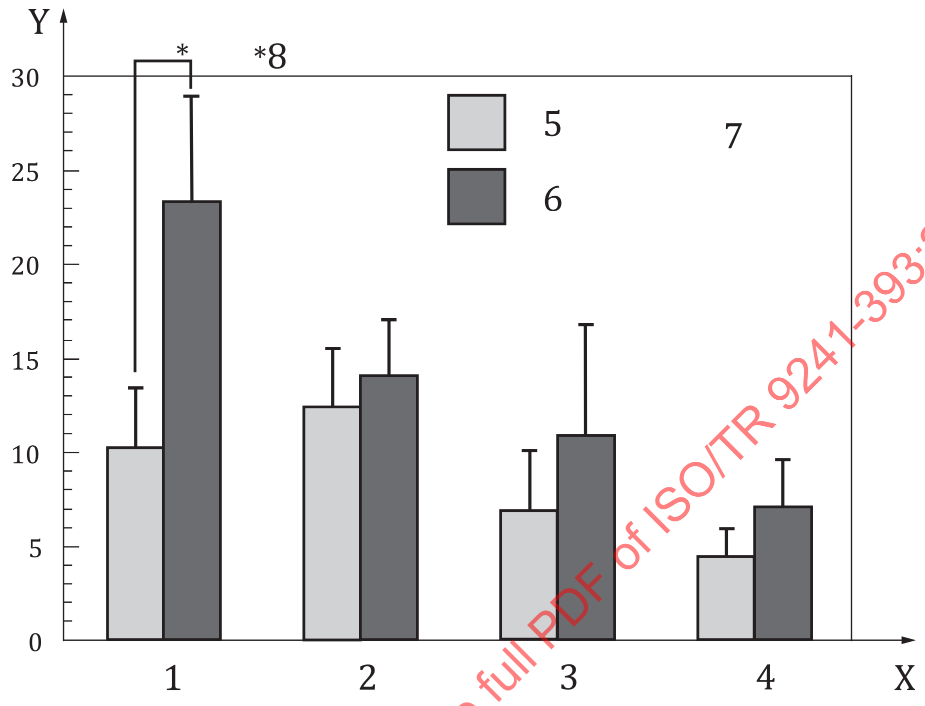
[a] The two conditions were separated in15 min washout period.

6.2.18 Stereoscopic image

6.2.18.1 Key aspect

Effects of stereoscopic image on VIMS: stereoscopic presentation often triggers the subjective increase of VIMS, especially in nausea level when the image motion is relatively large. The objective indices, on the other hand, (e.g. postural responses, activities of autonomic nervous system, changing of eye functions) do rather remain constant during stereoscopic observation.

6.2.18.2 Description



Key

X SSQ
Y score
1 nausea
2 oculomotor
3 disorientation
4 total score
5 2D image
6 3D image
7 n = 34
8 p < 0,05

NOTE Sub-score of “nausea” of SSQ significantly higher in the 3D than in the 2D condition, while the other sub-scores and the total score also showed the similar tendency (Ujike et al., 2011).

Figure 4 — Effects of 3D/2D presentation on subjective ratings for sickness

Sickness ratings were obtained after observers viewed images presented with a size of 50° on a projection display with four different combination conditions of viewing (monoscopic/stereoscopic) and image motion (still/moving) sub-conditions. The results showed that there was no significant effect of viewing sub-condition, and marginal effect of image motion sub-condition on sickness ratings (Figure 4 in Ijsselsteijn et al., 2001).

Naqvi et al. (2013) presented 2D and 3D movies on a 102 cm (40’’) 3D LC display to the observers with between-subject design. The results showed that the SSQ total score and two sub-scores (nausea and disorientation) were significantly larger with 3D movie than with 2D (Figure 1 in Naqvi et al., 2013). However, LF/HF ratio obtained from electrocardiography (ECG) did not show significant difference between the 2D and 3D movies (Figure 2 in Naqvi et al., 2013).

Solimini (2013) conducted a prospective carryover study in which effects of watching 3D movie compared to 2D movie was examined with 497 participants using the simulator sickness questionnaire. The results showed significant effect of 3D movie on visually induced motion sickness (Figure 1 in Solimini, 2013).

Pölönen et al., (2013) reported experiments in which a total of 130 children and adults participated in seven different setups, in which both projection screen and plasma display were used, both film viewing and game playing, and 2D and 3D images were included. The results showed no significant change of visually induced motion sickness between 2D and 3D images (Figure 6 in Pölönen et al., 2013).

Keshavarz and Hecht (2012) conducted two experiments. In the first experiment, video clips of a roller coaster ride were presented with four different combinations of realism of images (real vs. simulated) images and presentation types (2D vs. 3D) of images. In the second experiment, video clips of a bicycle ride were presented with four different combinations of presentation types (2D vs. 3D) of images and sound (on vs. off). The results showed that, in the first experiment, the highest sickness scores were obtained with 3D and real images, while the scores in other three conditions were not significantly different (Figures 2 and 3 in Keshavarz and Hecht, 2012). In the second experiment, the 3D images showed a significant effect on sickness scores, while sound did not have significant effect (Figure 7 in Keshavarz and Hecht, 2012).

Using 3D images, the effects of dynamic motion, image types (real vs. CG) and fixation were examined by Wibirama and Hamamoto (2014). They found that nausea and disorientation scores of simulator sickness questionnaire increased as amount of dynamic motion increased, while fixation decreased the scores. Moreover, CG images induced less scores of nausea and disorientation than real images (Fig.2 in Wibirama and Hamamoto, 2014).

The effect of 3D images was examined by Ujike and Watanabe (2011), in which CG images were presented on a stereoscopic 3D display with 2D and 3D modes. They found that a sub-score of nausea of simulator sickness questionnaire significantly higher in the 3D than in the 2D condition (Figure 4 in Ujike and Watanabe, 2011; see also Figure 4).

Häkkinen et al. (2006) used a binocular virtual eye-wear display and a tabletop display for presenting two different types of gaming: one is dynamic car racing game and the other is a static car racing game. The results showed that the highest sickness levels were obtained with dynamic car racing game, with which display types did not have effects on symptom levels (Figures 1 and 3 in Häkkinen et al., 2006).

6.2.18.3 Applications

This factor is useful for considering the effects of stereoscopic observation, which can be presented on the various types of displays (TV, screen, virtual display, handy game machine etc.).

6.2.18.4 Constraints

There are not enough data concerning about the relationship between visual fatigue from stereoscopic images and VIMS.

6.2.18.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 22.

Table 22 — Methods used in the factor — Stereoscopic image

	(i) Ijsselsteijn et al. (2001)	(ii) Naqvi et al. (2013)	(iii) Solimini (2013)	(iv) Pölönen et al. (2013)
Participants	24 (11 males, 13 females; age range, 18 to 30, average 23,5; a height of under 1,85 m)	19 (2D), 20 (3D)	497 (Age <20 (7,6 %), 20-29 (69 %), 30-39 (14,9 %), 40-49 (2,4 %), ≥50 (6.0 %); female (55,7 %), male (44,3 %)) . Eye glasses use: glasses (29,2 %), lens (15,3 %), no glasses (55,5 %). Very often in a typical month of headache (14,9 %), motion sickness (6.0 %), dizziness/vertigo (18,1 %), anxious person (35,6 %). Participants of 35,6 % reported to use of computer and/or video game console for more than 5 h per day.	130 (six participants were excluded because of visual function problems, and seven participants were removed from the analysis due to severe eyestrain (n = 2) or VIMS(n = 5); Children (age range, 8 to 15) 58, adults (age range, 25 to 46) 60).
Display device	Polarized two images were projected on a large curved display	Passive 3D LCD TV (LG)	Theatre screen	127 cm (50 ") 3D TV and 3D projector
Display content	Moving image: 100 s of a continuous piece of footage shot by a small stereoscopic camera positioned on the hood of a rally car traveling at speed around an off-road rally track. Still image: consisting of a still frame where the camera is situated by the side of the rally track awaiting the rally car to drive by.	A view captured from a camera while moving along streets with yaw and roll rotation. A one min pitch and one min roll were repeated alternately. Amplitude of rotation was 30° with temporal frequency of 0,167 Hz.	2D and 3D movies.	Game playing (“Modern Warfare 2” for adults, “Alice in Wonderland” for adults and children), and film viewing (“Alice in Wonderland”).
Display resolution	N/A	Not specified	N/A; real screen	127 cm (50 ") 3D TV (1 920 × 1080) pixels and 3D projector (1 280 × 720) pixels
Display size	Whole visual field 50° view (1,9 m × 1,45 m)	40 inch	N/A; Real screen	127 cm (50 ") 3D TV (1,11 m × 0,62 m, 27°) and 3D projector (2,24 m × 1,26m, 48°)
Viewing distance	Approximately 2,0 m	Not specified	Not specified	A few meters (up to 2,5 m)

Table 22 *(continued)*

	(i) Ijsselsteijn et al. (2001)	(ii) Naqvi et al. (2013)	(iii) Solimini (2013)	(iv) Pölönen et al. (2013)
Chin/head-rest	None	Not specified	Free viewing	None
Fixation	None	Not specified	None	
Viewing period	20 min	Eye close (5 min), Eye open (5 min), Movie (10 min)	Not specified	30 min × 4 for game, and 40 min × 2 for film.
Experiment conditions	Four conditions: (a) monoscopic with still image, stereoscopic, (b) monoscopic with moving image, (c) stereoscopic with still image, (d) stereoscopic with moving image.	Two conditions: (a) 2D movie, and (b) 3D movie	Two conditions: (a) 2D movie, and (b) 3D movie	There were seven group conditions: (a) A-T-3D-F, (b) A-P-3D-F, (c) A-P-3D-G, (d) A-P-2D-G, (e) C-T-3D-F, (f) C-P-3D-F (g) C-P-3D-G, using the abbreviations of adult (A) or children (C), TV (T) or projector(P), 3D or 2D, and film (F) or game (G)
Experimental design	Within subject design	Between subject design	Within subject design	Between subject design
Physiological measurements	Potural responses with Flock of Birds (FOB) magnetic position tracker	LH/HF	None	Every 30 min (0, 30, 60, 90, 120) during game playing: Near point of accommodation, heterophoria At 40 min after starting, and at the end of film viewing: Near point of accommodation, heterophoria
Psychological measurements	After observation: Visual Analog Rating Scale for presence, vection and involvement	At the end of the movie: SSQ	Before/after each movie: SSQ	Every 30 min (0, 30, 60, 90, 120,) during and one hour after game playing: VSQ(Visual Symptoms Questionnaire), SSQ At 40 min after starting, and at the end of film viewing: VSQ, SSQ

Table 22 — Methods used in the factor — Stereoscopic image

	(v) Keshavarz (2012)	(vi) Wibirama et al. (2014)	(vii) Ujike et al. (2011)	(viii) Häkkinen et al. (2005)
Participants	Exp.1: 78 (19 male and 59 female; age range, 24,37 ± 5,38), Exp.2: 69 (35 male and 34 female; age range, 22,99 ± 4,28)	First session: 20 (15 male and 5 female; age average, 22,25), Second session: 20 (17 male and 3 female; age average, 22,65)	34 (25 females and 9 males; age range, 21-77)	30 (15 males and 15 females; age average 24,4, range 18-42)
Display device	A stereoscopic projector (projection design F10 AS3D)	A stereoscopic display	3D LC displays (GD-463D10, JVC), 60 Hz	Exp.1 and 2: Olympus EyeTrek FMD-700 head-worn display, Exp.3 and 4: Sony Trinitron GDM-F520 display
Display content	Exp.1: A real and a simulated video sequence of the same roller coaster, Exp.2: A real video sequence generated by two cameras mounted on handlebars of an ordinary bicycle.	Fisrt session: CG movie (city walk-through), Second session: real movie (a scenery of front seat of roller coaster).	CG movie traveling along streets, turning both right and left twice every one minute of travel, with pitch and roll motion (30° amplitude, 0,167 Hz), alternatively every one minute.	Computer games: “Need For Speed Underground” in Exp.1 and 3, “Slicks’n Slide 1,30d” in Exp.2 and 4
Display resolution	Exp.1: (800 × 600) pixels, Exp.2: (600 × 480) pixels	(1 920 × 1 080) pixels	(1 920 × 1 080) pixels (960 × 1 080, side-by-side) pixels	Exp.1 and 2: (800 × 600) pixels, Exp.3 and 4: Not specified
Display size	Exp.1: (300 × 196) cm (60 × 43)°, Exp.2 (300 × 196) cm (41 × 28)°	Not specified [probably about 61 cm (24 inches)]	(33,8 × 18,9)°	Exp.1 and 2: (30 × 30)°, Exp.3 and 4: (22,0 × 16,6)°
Viewing distance	2 m (Exp.1), 3 m (Exp.2)	70 cm	172 cm	Exp.1 and 2: N/A, Exp.3 and 4: 1 m
Chin/head-rest	Chin rest	Not specified (probably chin rest)	None	Not specified
Fixation		A white point on each movie for fixation condition	None	Not specified
Viewing period	Exp.1: 14 min 24 s (8 times of 1 min 48 s) for real video, 14 min 4 s (10 times of 1 min 25 s) for simulated video, Exp.2: 14 min 21 s	5 min	10 min	40 min

Table 22 *(continued)*

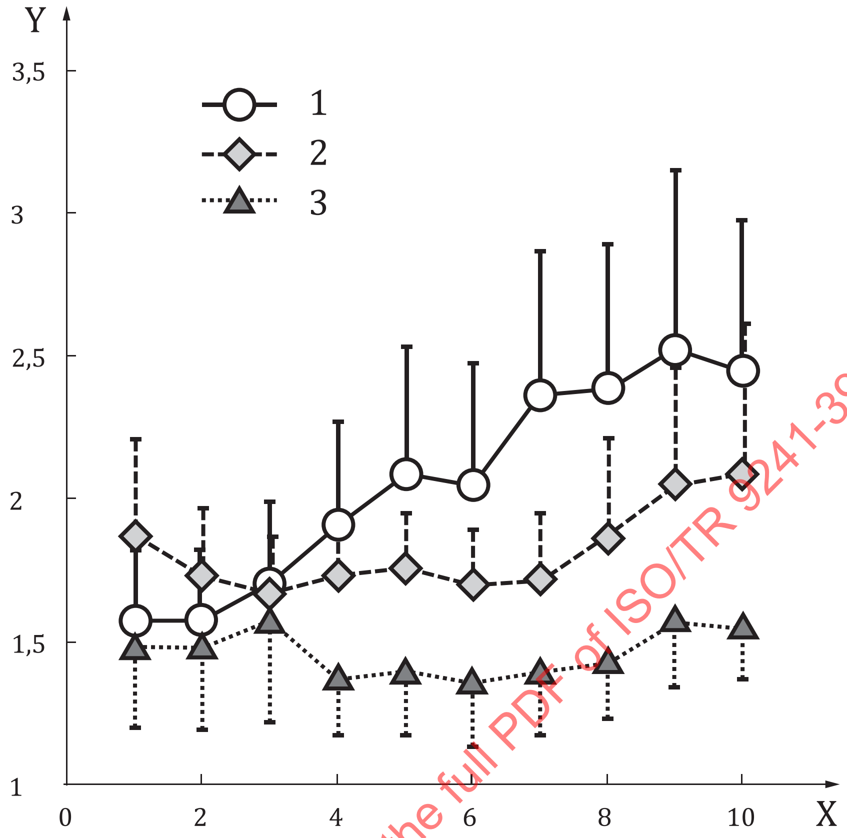
	(v) Keshavarz (2012)	(vi) Wibirama et al. (2014)	(vii) Ujike et al. (2011)	(viii) Häkkinen et al. (2005)
Experiment conditions	Exp.1: Combinations of 2D/3D and real/simulated, Exp.2: Combinations of 2D/3D and with/without sound	With or without fixation point for the first and second session	(a) 2D image, (b) 3D image	Combinations of two display devices, and two game contents, as a total of four experiments.
Experimental design	Between subject design	Between subject design	Within subject design	Within subject design
Physiological measurements	Before experiment: romberg test (vestibular dysfunction), Titmus test (stereo acuity)	During viewing: ECG (LF/HF), Gaze tracking	During viewing: ECG	None
Psychological measurements	Every 1 min in Exp.1 and 2: FMS scale, Prior, immediately after, five hours after observation in Exp.1: SSQ, Prior, immediately after observation in Exp.2: SSQ	At the end of the session: SSQ	During viewing: subjective comfortability measured every one minute, Before/after viewing: SSQ	Before/after each experiment: SSQ, VSQ(Visual Symptoms Questionnaire), After each experiment: mood curve, EVEQ (Experience Questionnaire)

6.2.19 Prediction signs for motion

6.2.19.1 Key aspect

Effects of prediction signs for motion on VIMS: visually presented prediction signs for motion seems to reduce VIMS in psychological or physiological aspects. The representation of these signs could be a virtual guiding avatar, unobtrusive cues for trajectory and pictorial signs for the locations of acceleration.

6.2.19.2 Description



Key

X phase

Y averaged LF/HF ratio

1 no sign

2 750 ms prior

3 3 500 ms prior

NOTE The activity of sympathetic nervous neuron system was increased through observing driving simulator when no predictive sign was presented (circle and solid line). This, on the other hand, physiological index remained the initial values when the pictorial prediction sign was presented 3500ms before the acceleration event (triangle and dotted line, Watanabe et al., 2007).

Figure 5 — Effects of visually presented prediction sign for sickness

Moving image through front window of a driving simulator was presented in four experimental conditions of virtually guiding avatar (VGA) and its motion. After each trial of viewing images, participants completed questionnaires about revised simulator sickness questionnaire (RSSQ), presence and enjoyment. The results showed that RSSQ scores in the conditions 3 (only rotation cues, which predicted the near future direction of observer, was added to the VGA) and 4 (rotation plus translation cues, which predicted the both of near future direction and location of observer, were added to the VGA) were both significantly lower than those in condition 1 (no-signs) (Figure 5 in Lin et al., 2004). In condition 2, VGA was fixed to the earth coordinate.

Moving image through front window of a driving simulator, again, was presented in three cue conditions about information of turns provided by visual path: detailed cues, simplified cues, and no cues conditions. After each trial of viewing images, participants completed questionnaires about simulator sickness, presence and enjoyment. The results indicated significant effect of simplified and detailed path cues on reducing simulator sickness scores compared to no cues condition (Lin et al., 2005).

Participants viewed moving images simulating forward motion while sitting on a chair on a motion base system. The motion base simulated acceleration and deceleration in some randomized period. There were three experimental conditions about the predictive sign of the acceleration event: no sign, 750 ms prior to the event, and 3 500ms prior to the event. The results indicated that the activity of sympathetic nervous system increased through observing driving simulator when no predictive sign was presented. The physiological index, however, remained the initial values when the predictive sign appeared 3 500 ms prior to the acceleration event (Figure 7 in Watanabe et al., 2007; see also Figure 5).

6.2.19.3 Applications

This factor is useful for reducing the effects of realistic motion contents in a virtual environment such as the driving simulator.

6.2.19.4 Constraints

There are three experimental data concerning about the relationship between visually presented predict signs for motion and VIMS.

6.2.19.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 23.

Table 23 — Methods used in the factor — Prediction signs for motion

	(i) Lin et al. (2004)	(ii) Lin et al. (2005)	(iii) Watanabe et al., (2007)
Participants	12 (8 female and 4 male; age range, 18-35)	12 (7 female and 5 male; age range, 18-55)	22 (9 male and 13 female; male age, 23,8 ± 1,9, female age, 24,8 ± 3,0)
Display device	CAVE (3 screens) + driving simulator	CAVE (3 screens) + driving simulator	CAVE (4 screens) + motion base
Display content	CG image of Crayonland (cartoon like world, including a cabin, pond, flowerbeds, and forest)	CG image of Crayonland (cartoon like world, including a cabin, pond, flowerbeds, and forest)	CG image of driving course (acceleration, constant velocity, and deceleration, constant velocity). The time intervals for the four events are 28,5 ± 5,7 sec
Display resolution	Three screens of (800 × 600) pixels, (horizontally arrayed)	Three screens of (800 × 600) pixels, (horizontally arrayed)	None
Display size	(230 × 175) cm per screen, 220° with 3 screens	(230 × 175) cm per screen, 220° with 3 screens	(3 × 3) m
Viewing distance	None (probably 2 m)	None (probably 2 m)	1,5 m
Chin/head-rest	None	None	None
Fixation	None	None	None
Viewing period	120 s for each condition	120 s for each condition	16 min

Table 23 *(continued)*

	(i) Lin et al. (2004)	(ii) Lin et al. (2005)	(iii) Watanabe et al., (2007)
Experiment conditions	(a) no avatar (VGA), (b) an earth-fixed VGA without cues for turns prediction, (c) an earth-fixed VGA that used rotation to provide cues for predicting turns, (d) a non-earth-fixed VGA that used both rotation and translation to provide cues for predicting turns.	(a) detailed cues for turn, (b) simplified cues for turn, (c) no cues for turn, (d) informed, detailed cues for turns.	(a) no signs, (b) signs 750 ms before acceleration events, (c) signs 3 500 ms before acceleration events.
Experimental design	Within subject design	Within subject design	Within subject design
Physiological measurements	None	None	LH/HF
Psychological measurements	Revised SSQ Questionnaire (Kim, 1999), an enjoyment, engagement, and immersion questionnaire (Lin et al., 2002, 2005)	Revised SSQ Questionnaire (Kim, 1999), an enjoyment, engagement, and immersion questionnaire (Lin et al., 2002, 2005)	Graybiel score

6.3 Effective factors: Visual environmental factors

6.3.1 General

Although VIMS is basically induced by image motion, or more specifically, global image motion, there are some effective factors affecting the severity of VIMS among different viewing environments. One of the well-known environmental viewing factors is image size in the visual field; the severity of VIMS increases with image size in the visual field. Moreover, the literature reports the existence of a “rising point” and a “saturation point” in terms of the image size in visual field (see 6.3.2). Other well-known factors can be duration of image motion and repeated exposure to image motion. Actually, the literature reports that the severity of VIMS increases when duration of image motion becomes longer and that the severity decreases when exposures to image motion are repeated within a certain interval (see 6.3.5). Another well-known factor in this category, but directly related to HMD-presentation, might be the time delay between head movement of observers and the corresponding change of images. Although a larger time delay is widely thought to be provocative to induce VIMS, the literature reports that variation of time delay is the factor to induce severe VIMS (see 6.3.4). In 6.3.4, the factor of time delay was considered only for the VR type of HMD-presentation, which covers the whole visual field without a see-through image. When the AR type of HMD-presentation, showing both the virtual image and the real see-through image, is considered, a time delay causes not only a temporal mismatch between head position and virtual image position, but also a temporal mismatch between virtual image position and real see-through image position. This may affect the severity of VIMS, which should be further investigated.

Another visual environmental factor, which is often produced while it is not necessarily recognized, is the perspective difference between capturing and rendering images. However, this effect is rather opposite to what may be intuitively supposed; the literature reports that the severity of VIMS decreases when the perspective difference between capturing and rendering images increases (see 6.3.3).

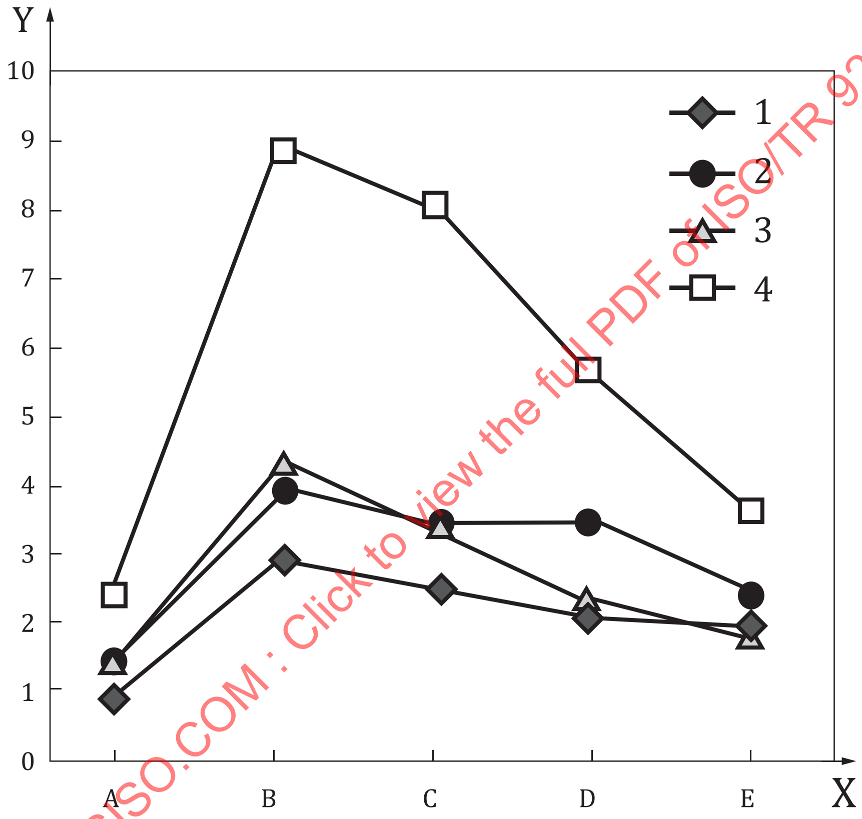
In the category of viewing environment, there are some factors reducing the severity of VIMS without manipulating moving images themselves. One of these factors is changes of the illumination colour; when the colour of illumination was changed during nauseating image motion, the severity of VIMS became slightly smaller than when the colour was not changed (see 6.3.6). Moreover, subjective scores of VIMS decreased when either pleasant musical sounds (see 6.3.7) or a pleasant odour was presented with nauseating global image motion (see 6.3.8).

6.3.2 Image size in visual field

6.3.2.1 Key aspect

Effects of image size in visual field: the severity of VIMS increases, when the size of the visual angle of moving images, including dynamic motion, increases. The effect becomes clear when the size of the visual field is larger than 30° and the effect saturates below the horizontal size of 180°.

6.3.2.2 Description



Key

X phase

Y averaged SSQ total score

A prior to viewing

B just after viewing

C 15 min later

D 30 min later

E 45 min later

1 28 cm (11 inch) display

2 33 cm (13 inch) display

3 51cm (20 inch) display

4 94 cm (37 inch) display

Figure 6 — Effects of image size in visual field on SSQ total score (Ujike et al., 2005)

The same video images are presented on four different display sizes (11, 13, 20, 37) inch using the same viewing distance (1,0 m) in Ujike et al. (2005), and SSQ was conducted five times, before and just after viewing the image, and every 15 min until 45 min after the viewing for each display size. The total scores shown in Figure 6 in Ujike et al. (2005) were significantly the largest for the 37-inch display than for those with the 20-, 13- and 11-inch displays.

The same video images are presented in four different sizes [(33, 61, 83, 100)° in the horizontal direction] of FOV using the same display but different image areas with a constant viewing distance in Emoto et al. (2008). They found that the SSQ total score shown in Figure 4 in their literature (Emoto et al., 2008) significantly increases with width of the horizontal field of view. Multiple comparisons with Wilcoxon signed-rank test showed significant differences between pairs of (pre-exposure, 83°), (pre-exposure, 100°), (61, 83)°, and (83, 100)°.

Images presented in a driving simulator are used with four different size of FOV [(60, 100, 140, 180)° in horizontal] in Lin et al. (2002). For the logarithmic SSQ scores shown in Figure 4 in Lin et al. (2002), all pairwise comparisons are significant except for the pairs of (60, 100)° and (140, 180)°.

6.3.2.3 Applications

This factor is useful for considering the effects of visual image size of a moving image.

6.3.2.4 Constraints

The investigated conditions were limited so that the resolution of images was changed with image size.

6.3.2.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 24.

Table 24 — Methods used in the factor: Image size in visual field

	(i) Ujike H, Yokoi T and Saida S (2005)	(ii) Emoto M, Sugawara M and Nojiri Y (2008)	(iii) Lin JJ-W, Duh HBL, Parker DE, Abi-Rached h and Furness TA (2002)
Participants	134 (36 males, 98 females; age range, 19 to 71, 35,4 ± 12,5)	15 (1 male, 14 females; age range, 27 to 37, average, 32,4)	10 (5 males, 5 females; age range, 20 to 31)
Display device	Four different displays: (a) 28 cm (11 inch) LCD display, (b) 33 cm (13 inch) LCD display, (c) 51cm (20 inch) LCD display, (d) 94 cm (37 inch) LCD display.	Super Hi-Vision video system, consisting of 436 inch screen with two different projectors for R,B and for G (approx.5 000 lumen.)	Three projectors, in a real drive driving simulator including a full-size real car, with stereo glasses
Display content	Video images (5 min gray + 20 min video footage + 2 min gray); 20 min video footage was that provoked an incident of VIMS in Japan.	Video images (5 min stabilized sequence +10 min vibrating sequence); motion vector of original sequence was obtained and stabilized sequence was made by compensating the motion vector, while vibrating sequence was made by thrice multiplying the amplitude of the motion vector.	A virtual world, Crayola-land, was generated. Continuous roll oscillation at 0,2 Hz was combined with the motion path.
[a] The four conditions were used for 10 min vibrating sequence, while display size of 10° in horizontal was used for 5 min stabilized sequence.			

Table 24 *(continued)*

	(i) Ujike H, Yokoi T and Saida S (2005)	(ii) Emoto M, Sugawara M and Nojiri Y (2008)	(iii) Lin JJ-W, Duh HBL, Parker DE, Abi-Rached h and Furness TA (2002)
Display resolution	(a) (854 × 480) pixels (11 inch), (b) (640 × 480) pixels (13 inch), (c) (640 × 480) pixels (20 inch), (d) (1 366 × 768) pixels (37 inch).	(a) (1 920 × 1 080) pixels (33° in horizontal), (b) (3 840 × 2 160) pixels (61°), (c) (5 760 × 3 240) pixels (83°), (d) (7 680 × 4 320) pixels (100°).	Three screens of (800 × 600) pixels, (horizontally arrayed)
Display size	(a) (11 × 8)° (11 inch), (b) (15 × 11)° (13 inch), (c) (23 × 17)° (20 inch), (d) (34 × 26)° (37 inch).	Screen size was (9,8 × 5,6) m, when screen resolution was (7 680 × 4 320) pixels. The reduced display resolution directly corresponds to the size of the display.	Three of (230 × 175) cm
Viewing distance	1,0 m	4,0 m	Not specified
Chin/head-rest	Chin/head-rest with arm-rest	No chin/head-rest, but the viewers lay down on a fully reclined chair in the supine position	None
Fixation	None	None, but being instructed to look at around the centre of the screen	None
Viewing period	27 min (5 min gray +20 min video +2 min gray)	15 min (5 min stabilized sequence (baseline period) +10 min vibrating sequence (test period))	120 s
Experiment conditions	Four display size conditions: (a) 11 inch display, (b) 13 inch display, (c) 20 inch display, (d) 37 inch display.	Four display size conditions[a] (degrees in horizontal): (a) 33°, (b) 61°, (c) 83°, (d) 100°.	Four FOV conditions: (a) ±30° (60°), (b) ±50° (100°), (c) ±70° (140°), (d) ±90° (180°).
Experimental design	Between subject design	Within subject design	Within subject design
Physiological measurements	None	During stimulus period: Heart rate variability, skin temperature deviations	None
Psychological measurements	Every 1 min during stimulus period: “General discomfort” of SSQ Before/after stimulus period: SSQ	Before/after stimulus period: SSQ During stimulus period: SSCQE (Single Stimulus Continuous Quality Evaluation)	Pre-test period: SSQ E2I (Evaluating engagement, enjoyment, and immersion) After each stimulus period: SSQ, E2I

[a] The four conditions were used for 10 min vibrating sequence, while display size of 10° in horizontal was used for 5 min stabilized sequence.

6.3.3 Perspective difference between capturing and rendering images

6.3.3.1 Key aspect

Effects of perspective difference between capturing and rendering of images: the severity of VIMS decreases when the visual field size of moving image increases in difference between shooting of images and presentation of those images.

6.3.3.2 Description

For focusing on the effects of perspective difference between capturing and rendering of images, van Emmerik et al. (2011) manipulated both internal FOV (FOV of captured images) and external FOV (FOV of rendered images). The results of MISC-A shown in Figure 5 in van Emmerik et al. (2011) are plotted both for their experiment (plotted with light grey dots) and for the experiment of Bos et al. (2010) (plotted with dark grey dots). By comparing the data in the two anchoring conditions between van Emmerik et al. (2011) and Bos et al. (2010) they found there is no significant difference. Moreover, the SSQ total score showed significant effects of session, and condition, which is the same pattern as described for MISC-A.

The data was fitted to a surface that can be described by the following equation:

$$i*iFOV+e*eFOV+|eFOV-iFOV|$$

where

$iFOV$ is the internal field of view;

$eFOV$ is the external field of view;

i is a constant of 0,013;

e is a constant of 0,058;

d is a constant of -0,022.

6.3.3.3 Applications

This factor is useful for considering the effects of visual image size of a shooting image relative to that of a presented image.

6.3.3.4 Constraints

The investigated conditions of global image motion seem limited to forward motion and some roll motion. Depending on what types of motion is included in moving image, the distortion appeared around the peripheral area of images, which can be more pronounced with the difference between iFOV and eFOV, may be more effective.

6.3.3.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 25.

Table 25 — Methods used in the factor — Field of view difference

	van Emmerik ML, de Vries SC, and Bos JE (2011)
Participants	40 (19 males, 21 females; age range, 17 to 46, average, 23,3 ± 4,8; MSSQ yielded a mean score of 53,1, representing the 63rd percentile of a normal population)
Display device	DLP projector
Display content	A movie consisting of four repetitions of a tour through a virtual environment walking at a speed of 13,6 km/h, and additional motion pattern of a rotation of the scene on the antero-posterior axis at a foot level with a peak amplitude of 16°, composed of three sines with periods of 7,2, 4,1, and 4 s.
Display resolution	(1 024 × 768) pixels
Display size	(1,46 × 1,09) cm [eFOV, (40, 60, 90)° at 200 cm, 126 cm, 76 cm]
Viewing distance	(200, 126, 76) cm
Chin/head-rest	Head rest attached to a comfortable office chair
Fixation	None
Viewing period	50 min or until well-being score reaching “5” or higher
Experiment conditions	Combinations[a] of the following iFOVs and eFOVs: iFOV: (60, 90)° eFOV: (40, 60, 90)°
Experimental design	Partially[b] within subject design
Physiological measurements	Before/after stimulus period: Postural sway using balance board
Psychological measurements	Before experiments: MSSQ, After each experimental trial: SSQ, During stimulus period: MISC.

[a] A combination of iFOV of 90° and eFOV of 60° was not used.

[b] Each subject only participated in three out of the five possible conditions.

6.3.4 Time delay in HMD

6.3.4.1 Key aspect

Effects of varying time delay in HMD: varying time delay, or latency, induces more severe VIMS among HMD users than constant latency, while additional constant latency to the original latency of HMD does not induce larger severity of VIMS than the original.

6.3.4.2 Description

An HMD was used to show the laboratory scene in front of participants by capturing images in Moss et al. (2011) using video camera mounted on top of the HMD. This set up enables to examine the effects of latency of HMD on VIMS without using head tracking which may include tracking errors producing variation of latency of the HMD. Three different constant latencies were added to the original latency of an HMD. Then, SSQ total scores (SSQ TS) were obtained before, during and after the experimental session, while the averaged peak SSQ TS value does not show any significant difference among different conditions of additional latency and no HMD condition (Figure 5 in Moss et al., 2011).

Almost the same experimental settings were used by St. Pierre et al. (2015) except the delay conditions. Those were two constant latency conditions, “baseline”, “constant”, and two other varying latency conditions, “fixed-frequency and fixed-amplitude”, and “fixed-frequency and varying-amplitude”. The averaged value of SSQ TS for varying latency conditions was significantly larger than that for constant latency conditions (Figure 5 in St. Pierre et al., 2015). Moreover, for sinusoidally varying latency of HMD, SSQ TS was larger with varying amplitude than with fixed amplitude (Figure 4 in St. Pierre et al., 2015).

6.3.4.3 Applications

This factor is useful and important for considering the reduction of the effects of latency in HMD system on VIMS; the latency of HMD represents the time between a head movement and change in the rendering of virtual environment in the display.

6.3.4.4 Constraints

The factor was examined with the devices that have a constant latency of either 40 ms or 70 ms, which can be smaller depending on the advancement of technology.

In practice, longer constant latency of HMD would induce larger severity of VIMS than the original, because variations of latency in HMD system would be produced by tracking error of head movements.

6.3.4.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 26.

Table 26 — Methods used in the factor — Time delay in HMD

	Moss JD, Austin J, Salley J, Coats J, Williams K, Muth ER (2011), Exp. 2	St. Pierre ME, Banerjee S, Hoover AW, Muth ER (2015)
Participants	29 (12 females, 17 males; age average, 21, range, 18 to 25), for No HMD condition, 19 (8 females, 11 males; age average 20, range 18 to 23)	120[a] (64 females, 56 males)
Display device	An HMD[b] (Kaiser Electro-Optics, ProViewTM XL 50)	An HMD (Kaiser Electro-Optics, ProViewTM XL 50)
Display content	Live video of a digitized view of the laboratory captured by a digital camera (Uniq Vision, Uniq UC-610CL) mounted on top of the HMD. The same image was presented to both eyes. For No HMD, the laboratory scene was seen directly.	Live video of a digitized view of the laboratory captured by a digital camera (Uniq Vision, Uniq UC-610CL) mounted on top of the HMD. The same image was presented to both eyes.
Display resolution	(1 024 × 768) pixels, 60 Hz, for No HMD, N/A	(1 024 × 768) pixels, 60 Hz
Display size	(40 × 30)°	(40 × 30)°
Viewing distance	N/A	N/A
Chin/head-rest	None (standing position)[c]	None (standing position)[d]
Fixation	No description, may be nothing	No description, may be nothing
Viewing period	48 s × 2 (practice sessions) 2 min × 5 (trials, 1 min break between the trials)	48 s × 2 (practice sessions) 2 min × 5 (trials, 1 min break between the trials)

[a] Individuals who self-reported a history of severe motion sickness were excluded.

[b] For No HMD condition, HMD was not used.

[c] A step ladder was used as a handrail to support balance.

[d] The participants were standing comfortably and grasping the back of the step ladder with both hands.

[e] The task was to perform "object location task", in which active head movements were made, every 3 s, to locate eight different objects in the laboratory based on the name and direction of the objects. Experimental sessions were separated by 7 days.

[f] Experimental sessions were separated by 7 days.

[g] $Latency = A\sin(2\pi ft) + K + B$, where t is time.

Table 26 *(continued)*

	Moss JD, Austin J, Salley J, Coats J, Williams K, Muth ER (2011), Exp. 2	St. Pierre ME, Banerjee S, Hoover AW, Muth ER (2015)
Experiment conditions	Four conditions[e,f], including three levels of additional latency to the original (40 ms): (a) 0 ms, (b) 145 ms, (c) 300 ms, and (d) No HMD.	Four different conditions[e] of additional latency[g] to the original (70 ms): (a) base line (A =0 ms, f = 0 Hz, K = 0 ms, B = 70 ms), (b) constant (A = 0 ms, f = 0 Hz, K = 200 ms, B = 70 ms), (c) fixed frequency, fixed amplitude (A = 100 ms, f = 0,2 Hz, K = 200 ms, B = 70 ms), (d) fixed frequency, varying amplitude (A = 20-100 ms, f = 0,2 Hz, K = 100 ms, B = 70 ms).
Experimental design	Between subject design, within three levels of additional latency conditions	Between subject design
Physiological measurements	None	None
Psychological measurements	(Before/between/after trials) SSQ	Before/between/after trials: SSQ, Motion Sickness Assessment Questionnaire (MSAQ), Before the experiment: Motion Sickness History Questionnaire (MSHQ)

a Individuals who self-reported a history of severe motion sickness were excluded.

b For No HMD condition, HMD was not used.

c A step ladder was used as a handrail to support balance.

d The participants were standing comfortably and grasping the back of the step ladder with both hands.

e The task was to perform “object location task”, in which active head movements were made, every 3 s, to locate eight different objects in the laboratory based on the name and direction of the objects. Experimental sessions were separated by 7 days.

f Experimental sessions were separated by 7 days.

g $Latency = A\sin(2\pi ft) + K + B$, where t is time.

6.3.5 Duration and repeated exposure to visual stimulus

6.3.5.1 Key aspect

Effects of exposure duration and repeated exposures: when an exposure to visual motion becomes longer, the severity of VIMS increases. However, when exposures to visual motion are repeated with a certain interval, the severity of VIMS gradually decreases.

6.3.5.2 Description

Total of 938 cases of exposure period of flight simulators (helicopter flight) are re-examined. When the simulator data were divided into four categories (0 h to 1 h, 1 h to 2 h, 2 h to 3 h, 3 h or more) of exposure period, a significant linear trend is found (Figure 1 in Kennedy et al., 2000). The variance of each data point is rather large, possibly because the data were obtained from different simulators, and then, different scenario of the simulators.

From a single simulator of a training helicopter, a total of 53 records of sickness scores across seven consecutive simulated flights were examined. From the analysis, a significant decrease in sickness against the flight number was found (Figure 2 in Kennedy et al., 2000). The decrement was significant for a linear trend, as well as for a quadratic trend.

6.3.5.3 Applications

This factor is useful and important for considering the effects of viewing period of moving visual images on VIMS. Moreover, it is useful for considering the reduction of VIMS by repetitive exposures to visual motion from the viewpoint of observers.

6.3.5.4 Constraints

First of all, the data shown was obtained with simulators, possibly equipped with a motion base, but not in the situation of those in which observers are stationary. Moreover, the data shown is useful simply in terms of qualitative considerations, because: (a) the rate of increment of sickness score during observing moving images depends on various factors of visual images and viewing conditions, and (b) the rate of decrement of sickness score across the repetitive exposures also depends on various factors, including interval period of repeated exposures.

6.3.5.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 27.

Table 27 — Methods used in the factor — Duration and repeated exposure of visual stimulus

	Kennedy RS, Stanney KM, Dunlap WP (2000) - Exposure duration	Kennedy RS, Stanney KM, Dunlap WP (2000) - Repeated exposure
Participants	938 cases	53 records
Display device	A variety of simulators of helicopter flight	A simulator of helicopter flight (TH-57C) at the Naval Air Station (NAS) Whiting, in Milton, Florida
Display content	A variety of scenarios of helicopter flight	Presumably a single scenario of helicopter flight (TH-57C)
Display resolution	N/A	N/A
Display size	N/A; possibly whole visual field	N/A; possibly whole visual field
Viewing distance	N/A	N/A
Chin/head-rest	N/A	N/A
Fixation	N/A; possibly none	N/A; possibly none
Viewing period	Categorized into four as duration conditions	N/A
Experiment conditions	Four different duration categorized for analysis: (a) 0 h to 1 h, (b) 1 h to 2 h, (c) 2 h to 3 h, (d) 3 h and more	Different number of simulated flights: one to seven
Experimental design	N/A	N/A
Physiological measurements	None	None
Psychological measurements	After each session: simulator sickness questionnaire with 26 items to be scored	After each session: simulator sickness questionnaire with 26 items to be scored

6.3.6 Changes in illumination colour

6.3.6.1 Key aspect

Reduction effects of changes in illumination colour: when a colour of light illuminating visual motion stimulus is changed to another colour, severity of VIMS can be slightly smaller.

6.3.6.2 Description

The experiment was conducted with six sessions, in which yaw rotation was presented for four minutes. In the first three sessions, visual stimulus was illuminated with either a red or green light, and in the last three sessions, the stimulus was illuminated with a light of a different colour. While magnitude estimate of motion sickness increased within sessions, the rate of the increment clearly decreased in the last three session after the changes in illumination colour (Figure 7 in Dobie et al., 1989). This indicates the reduction of motion sickness in changes of colour illumination. Moreover, this suggests the reduction of motion sickness in a subtle manipulation of environmental settings of motion sickness situation.

6.3.6.3 Applications

This factor may be useful for considering the reduction of VIMS by manipulating visual environmental factors, including illumination colour.

6.3.6.4 Constraints

The investigated conditions are limited to yaw motion, and illumination of red and green colour, which is not rather popular for an illumination light colour.

6.3.6.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 28.

Table 28 — Methods used in the factor — Changes in illumination colour

	Dobie TG, May JG, Dunlap WP, and Anderson ME (1989)
Participants	16 (male only (US Navy volunteers); age range, 18 to 27)
Display device	A rotating drum (diameter 150 cm, height 120 cm)
Display content	Alternating black and white stripes covered the inner surface of the drum; width of each stripe was 15 cm. Rotating velocity was 60°/s (or 10 rpm).
Display resolution	N/A; real objects
Display size	Whole visual field
Viewing distance	No description (maybe below 75 cm)
Chin/head-rest	Stabilizing head cup
Fixation	None
Viewing period	4 min for each trial. Total: 4 min × 5 trials × 6 sessions.
Experiment conditions	Colour of illumination light[a]: red or green (used in either the first or last three sessions)
Experimental design	Between subject design
Physiological measurements	None
Psychological measurements	At the last 30 sec of each trial: magnitude estimation of vection intensity, magnitude estimation of motion sickness, Before/After each session: symptomatology score obtained by scoring 21 different symptoms (general discomfort (0-3), fatigue (0-3), boredom (0-3), mental depression (0-1), drowsiness (03), headache (0-3), "fullness of head" (0-1), blurred vision (0-1), dizziness (0-1), change in salivation (0-3), sweating (0-3), faintness (0-1), aware of breathing (0-1), stomach awareness (01), nausea (0-3), burping (0-1), confusion (0-1), change in appetite (0-1), desire to move bowels (0-1), vomiting (0-1), and other (0-1)).

[a] Coloured acetate sheets (red or green) are positioned in front of lights.

6.3.7 Auditory stimulation

6.3.7.1 Key aspect

VIMS-reducing effects of pleasant music: If a dynamic movie was presented simultaneously with the pleasant musical sounds, VIMS scores were reduced. Music pleasant for general public had this effect, but it was more important that the music was pleasant for the particular observer who joined the experiment.

6.3.7.2 Description

The experiment was conducted by Keshavarz et al. (2014) with four conditions, in which different types of music simultaneously with moving images were presented: relaxing, neutral, stressful, and no music. For those different types of music, no clear significant effect on VIMS scores, such as the FMS score and the SSQ scores, was shown.

By restructuring the data based on the pleasantness ratings, the participants were categorized into three: pleasant, unpleasant, no music. Then, significant effects of music pleasantness and also of gender for the peak FMS score (Figure 4 in Keshavarz et al., 2014) and the SSQ sub-scores were shown. Moreover, for the time-course of the peak FMS-scores (Figure 2 in Keshavarz et al., 2014), a significant effect of time, a significant interaction for time and gender, and for a time and music pleasantness were shown.

6.3.7.3 Applications

This factor is useful for considering the influence of the type of music on VIMS induced by moving images which is simultaneously presented with the music.

6.3.7.4 Constraints

Moving images used in this research may not induce feeling of strangeness during simultaneous presentation of music. When moving images and music are not well matched, which induces feeling of strangeness, the effects of music shown in the result may be different.

6.3.7.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 29.

Table 29 — Methods used in the factor: Reduction effects of pleasant music

	Keshavarz B, Hecht H (2014)
Participants	93[a] (50 females, age average, 24,16 ± 4,40; 43 males, age average, 25,72 ± 5,17)
Display device	A projection screen (deduced from other reports of the authors)
Display content	A video showing a bicycle ride through the city of Mainz, Germany. The video was captured with a camera mounted on the handlebars of a bicycle.
Display resolution	(600 × 480) pixels, 60 Hz
Display size	(51 × 40)° [(191 × 144) cm]
Viewing distance	200 cm
Chin/head-rest	A chinrest
Fixation	None
Viewing period	14 min 15 s

[a] 20 participants ceased the experiment prematurely due to severe sickness or strong discomfort.

[b] The chosen songs were labelled among the subjects' peer group as each of the three types of music.

Table 29 *(continued)*

	Keshavarz B, Hecht H (2014)
Experiment conditions	Four conditions, consisting of three types of music[b] and no music: (a) relaxing music: instrumental music, (b) neutral music: pop music, (c) stressful music: electronic music, (d) no music: no music was presented.
Experimental design	Between subject design
Physiological measurements	None
Psychological measurements	Every 1 min during stimulus period: FMS scale, Before/after the experimental trial: SSQ, stressfulness with seven-point scale (1: very relaxing, ... 7: very stressful), pleasantness with seven-point scale (1: very pleasant, ... 7: very unpleasant).

[a] 20 participants ceased the experiment prematurely due to severe sickness or strong discomfort.

[b] The chosen songs were labelled among the subjects' peer group as each of the three types of music.

6.3.8 Odour simulation

6.3.8.1 Key aspect

Reduction effects of pleasant odour: when a pleasant odour is presented with visual motion stimulus, severity of VIMS can be reduced.

6.3.8.2 Description

The experiment was conducted by Keshavarz et al. (2015) with three conditions, in which different odour stimuli were presented: rose, leather, and no odour. In the pilot experiment, the authors confirmed that (i) rose is a pleasant odour, (ii) leather is an unpleasant odour, and (iii) the evaluation of "arousal" and "intensity" of those odours is not significantly different. Almost half of the participants in the "rose" and "leather" conditions had noticed each odour. (Therefore, the participants were categorized into four: (a) they noticed "rose" odour, (b) they noticed "leather" odour, (c) they did "not notice" any odour, and (d) they are in the "control" condition, in which no odour was presented.) For those participants who noticed the presented odour, the rose odour significantly reduced the severity of VIMS (in terms of SSQ scores, shown in Figure 3, and FMS score, shown in Figure 4, both in Keshavarz et al., 2015) compared to the participants who did not notice the odour. Moreover, the participants, whose odour sensitivity is higher, reported higher severity of VIMS.

6.3.8.3 Applications

This factor may be useful for considering the reduction of VIMS by manipulating the factors of the environment in which visual images are watched.

6.3.8.4 Constraints

The investigated conditions are limited to rose odour as a pleasant odour and leather odour as an unpleasant odour.

6.3.8.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 30.

Table 30 — Methods used in the factor: Reduction effects of pleasant odour

	Keshavarz B, Stelzmann D, Paillard A, Hecht H (2015)
Participants	62[a] (47 females, age average, 23,72 ± 6,62; 15 males, age average, 25,87 ± 6,24)
Display device	A projection screen
Display content	A video showing a bicycle ride through the city of Mainz, Germany. The video was captured with a camera mounted on the handlebars of a bicycle.
Display resolution	(640 × 480) pixels, 60 Hz
Display size	(51 × 40)° [(191 × 144) cm]
Viewing distance	200 cm
Chin/head-rest	A plastic chinrest
Fixation	None
Viewing period	14 min 15 s
Experiment conditions	(a) “pleasant” odour: rose odour[b], (b) “unpleasant” odour: leather odour[b], (c) “none”: no odour.
Experimental design	Between subject design
Physiological measurements	None
Psychological measurements	Every 1 min during stimulus period: FMS scale, After the experimental trial: SSQ, For the participants who noticed an odour during the experiment: SAM (Self-Assessment Manikin) rating scale of “valence”, “arousal”, and “intensity” of the odour. At the end of the experiment (for the participants in conditions (a) and (b)): COSS (The Chemical Odour Sensitivity Scale; containing 11 items that are rated using a 6-point Likert scale ranging from 0 (strongly disagree) to 5 (strongly agree)), IO (The overall Importance of Olfaction; consisting of 20 questions that are rated on a “0” (I totally disagree) to “3” (I totally agree)).

[a] 16 participants ceased the experiment prematurely due to severe VIMS.

[b] The odours were presented by a small odourless felt plate (0,10 mg) with five drops of 0,2 mg perfume oil of each odour.

6.4 Effective factors: Individual viewer factors

6.4.1 General

There are large individual differences in the severity of VIMS. What is the essential factor of the individual differences has not been well understood. However, some attributes, such as gender and age, have been discussed in terms of individual difference on susceptibility. Females are known to be more susceptible to VIMS than males; however, when the susceptibility to motion sickness was controlled between genders, the severity of VIMS was almost equivalent, indicating that the gender difference may be explained by some kinds of individuals’ prior experience and not by the inherent characteristics of gender (see 6.4.2). For the age difference, there are empirically known effects on traditional motion sickness, but not on VIMS. The known effects on motion sickness indicate that susceptibility to motion sickness has a peak at around 12 years (see 6.4.3).

Other factors categorized as individual viewer factors are active/passive viewing and fixation. When a moving image was viewed with interactive manipulation, such as in a driving simulator, the “drivers” (active viewer) do not suffer so much from VIMS as the “passengers” (passive viewers) (see 6.4.4). Moreover, the severity of VIMS becomes smaller when the viewers fixated a point during watching a moving image than when the viewers are viewing freely (see 6.4.5).

6.4.2 Gender

6.4.2.1 Key aspect

Different effects between females and males: females may be more susceptible to VIMS than males. However, this may be explained by differences in susceptibility of VIMS possibly produced by individuals' prior experience or some socialization processes and not by the inherent characteristics of gender.

NOTE For the possible causes of higher susceptibility to VIMS in females, see 6.4.3.

6.4.2.2 Description

Koslucher et al. (2015) exposed participants to back-and-forth movements of a room in which the participants were standing four times for a 10 min trial. Based on the participants' answer to the question about motion sickness after the exposure, motion sickness incidence of females (38 %, or 26 participants) showed a significantly larger value than males (9 %, or 4 participants).

Flanagan et al. (2005) exposed participants to visual yaw rotation produced by a cylindrical drum for 20 min in two conditions: the head movement and head restraint conditions. The composite scores of motion sickness questionnaire obtained before, just after, and 10 min after the exposure showed significant main effects for gender, head movement condition, and trial, and also a significant interaction between gender and trial (Figure 1 in Flanagan et al., 2005).

Graeber et al. (2002) exposed participants to visual yaw rotation produced by a cylindrical drum for a total of 35 min in four conditions. Each two of them are summarized and averaged for males and females, or for low and high susceptibility groups. The different gender groups were controlled in terms of susceptibility to motion sickness. The SSQ total scores obtained at resting periods during exposure, and those obtained after the exposure showed significant difference between different susceptibility groups, but not between different gender groups. Graeber et al. (2002) suggested the gender difference on subjective scores of VIMS may be explained by different susceptibility between different gender groups.

6.4.2.3 Applications

This factor may be useful for considering the effects of VIMS on observers or users of visual images, especially for different gender groups.

6.4.2.4 Constraints

Koslucher et al. (2015) found no difference of the severity of VIMS shown by averaged SSQ scores between females and males, both who reported "getting sick," although averaged SSQ scores between all females and all males are significantly different.

6.4.2.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 31.

Table 31 — Methods used in the factor — Gender

	Koslucher F, Haaland E, Malsch A, Webeler J, Stoffregen TA (2015)	Flanagan MB, May JG, Dobie TG (2005), Exp.2	Graeber DA and Stanney KM (2002)
Participants	114[a] (69 females, age average, 21,78 ± 2,23; 45 males, age average, 22,81 ± 3,43)	20[b] (10 females; 10 males)	40[c] (age average, 22, range 19 to 31)
Display device	A moving room	A cylindrical drum (diameter 153 cm, height 122 cm)	An optokinetic drum (diameter 213 cm, height 183 cm)
Display content	A cubical frame, 2,44 m on each side, mounted on wheels moves along anteroposterior axis. The wall and ceiling inside were covered with blue and marble-patterned paper. At the centre of the front wall was a map of US (28 × 19)°. Room motion was a sum of 10 sines, in the range of 0,02 to 0,4 Hz, (maximum amplitude was 2,5 cm).	Alternating black and white vertical stripes, 6 in wide, covered the inner surface of the drum. Rotating velocity was 60°/s (or 10 rpm).	A wallpaper pattern with 2,5 (1 inch) to 5,1 cm (2 inches) wide waves in various hues of blue.
Display resolution	N/A, real objects	N/A, real objects	N/A, real objects
Display size	Whole visual field	Whole visual field	Whole visual field
Viewing distance	Approximately average of 1,1 m at the centre of the front wall	No description (maybe below 75 cm)	No description (maybe below 100 cm)
Chin/head-rest	None (standing position)	A padded headrest	No description (possibly chinrest)
Fixation	No description	Instructed as to where to fixate so that the stimulus filled their entire field of vision	None
Viewing period	10 min × 4 sessions	20 min for each condition	35 min

[a] 27 participants ceased the experiment prematurely; 23 due to severe VIMS, 3 due to fatigue, and one due to time constraints.

[b] Four females discontinued the experiment in head movement condition, and one female and one male discontinued the experiment in head restraint condition.

[c] The participants were identified as having either a high or low susceptibility to motion sickness based on the motion history questionnaire (MHQ). The gender was balanced within each susceptible group.

Table 31 *(continued)*

	Koslucher F, Haaland E, Malsch A, Webeler J, Stoffregen TA (2015)	Flanagan MB, May JG, Dobie TG (2005), Exp.2	Graeber DA and Stanney KM (2002)
Experiment conditions	No specific conditions for independent variables	(a) head movement condition: participants performed alternating head movements to the rhythm of an audible metronome (0,5 Hz); pseudo-Coriolis effect, (b) head restraint condition: participants held their head against a padded headrest.	There were four conditions: (a) adaptation: one 35 min exposure at 60°/s, (b) incremental adaptation: one 35 min exposure, starting at 15°/s for 5 min, then 30°/s for 10 min, finally 60°/s for 20 min, (c) habituation: one 5 min exposure, one 10 min exposure, and one 20 min exposure, all at 60°/s, with a 48 hours interval period, (d) incremental habituation: one 5 min exposure at 15°/s, one 10 min exposure at 30°/s, and one 20 min exposure at 60°/s, with a 48 hours interval period.
Experimental design	N/A, all the participants participated once	Between subject design	Between subject design
Physiological measurements	None	None	None
Psychological measurements	Before/after the experiment: SSQ, question whether the participant was motion sick or not, Before the experiment: anthropometric measurements	Before/after, and further 10 min after the experiment: motion sickness questionnaire (24 items to be scored in 4-point scale), Every 1 min during exposure, and at the end of the experiment: motion sickness rating (0 to 10), vection intensity (0 to 10)	Before the experiment: motion history questionnaire Before/during/after exposure period: SSQ

[a] 27 participants ceased the experiment prematurely; 23 due to severe VIMS, 3 due to fatigue, and one due to time constraints.

[b] Four females discontinued the experiment in head movement condition, and one female and one male discontinued the experiment in head restraint condition.

[c] The participants were identified as having either a high or low susceptibility to motion sickness based on the motion history questionnaire (MHQ). The gender was balanced within each susceptible group.

6.4.3 Gender – Menstrual cycle -

6.4.3.1 Key aspect

Variation of susceptibility to VIMS corresponding to menstrual cycle: for females, susceptibility to VIMS varies over the menstrual cycle, in which certain days the susceptibility becomes higher than that in other days. This may explain a part of the results indicating that females may be more susceptible to VIMS than males.

NOTE For the higher susceptibility of VIMS for females, see 6.4.2.

6.4.3.2 Description

Clemes and Howarth (2005) exposed participants to gaming video images with HMD. The female participants, categorized as “Experimental Group A”, who exhibited expected variation of hormone levels according to menstrual cycle, showed a significant increase in susceptibility to VIMS on day 12 of their cycle (see Figure 4A in Clemes and Howarth, 2005). However, no change in susceptibility was observed for a female control group who takes a combined monophasic oral contraceptive (see Figure 4C in Clemes and Howarth, 2005) nor for a male control group. Moreover, for the female participants, categorized as “Experimental Group B”, whose cycle could not be precisely followed by the hormone analysis, any consistent variation in susceptibility could not be observed over the cycle.

6.4.3.3 Applications

This factor may be useful for considering the effects of VIMS on observers or users of visual images, especially for considering the effects on female group.

6.4.3.4 Constraints

Clemes and Howarth (2005) found susceptibility variation of VIMS for a part of naturally menstrual-cycling women; however, they could not detect the variation for the remaining naturally cycling women, which may be simply caused by the condition that they could not set the experiment days on those falling in line with peaks and troughs of ovarian hormone levels.

6.4.3.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 32.

Table 32 — Methods used in the factor — Gender — Menstrual cycle

	Clemes SA, Howarth PA (2005)
Participants	48[a] (32 females, 16 males): (a) Experimental group: 16 premenopausal females (age average, 25,1 ± 5,6) whose menstrual cycles are natural; they were divided into two sub-groups, (a1) experimental group A, 9 females who exhibited expected variation of hormone levels according to menstrual cycle, (a2) experimental group B, 7 females whose menstrual cycle could not be precisely followed by the hormone analysis, (b) Oral Contraceptive group (OC group; the first control group): 16 premenopausal females (age average 23,3 ± 4,8) who take a combined monophasic oral contraceptive for remaining the dose of the exogenous hormones, (c) Male group (the second control group): 16 males (age ave. 23,1 ± 4,7).

[a] During a screening session, potential participants who did not appear to be susceptible to VIMS were excluded.

[b] The order of testing was balanced across the female participants, to minimize the influence of any primacy or recency effects.

[c] For female participants, the cycle is their menstrual cycle, and then, those four days fall in line with peaks and troughs of ovarian hormone levels. For the participants in OC group, day 5 corresponded to day 5 of their “pill-free” week.

Table 32 *(continued)*

	Clemes SA, Howarth PA (2005)
Display device	A Virtuality Dynovisor Head Mounted Display (0,75 kg) connected to a Sony PlayStation 2 console
Display content	A racing game called “Wipeout Fusion”, in which participants race a hovercraft using a power pad controller. The hovercraft can move left, right, up, down, and in a rolling motion.
Display resolution	[263(h) × 230(v)] pixels
Display size	50° (h) × 50° (v)
Viewing distance	N/A
Chin/head-rest	A chinrest
Fixation	None
Viewing period	20 min, or if it is before reaching 20 min, viewing stops when reaching a “sickness rating” of 4
Experiment conditions	For different days[b] of a cycle[c] of 28 days: (a) day 5, (b) day 12, (c) day 19, (d) day 26.
Experimental design	Within subject design
Physiological measurements	For confirming the menstrual cycle phase of the female participants, the following hormone analysis was performed: measurement of salivary estradiol and progesterone levels
Psychological measurements	Every 1 min during stimulus period: Standard sickness rating in 4-point scale, Before/after the experimental trial: Motion sickness symptoms questionnaire adapted from SSQ, Four standard metrics were used to analyse the results: 1) The mean score of “standard sickness rating” for each minute for each group of participants, 2) The sum of the “standard sickness ratings” reported over 20 min viewing period, 3) The nausea score in 7-point scale included in “motion sickness symptoms questionnaire”, 4) The time that elapsed before participants first reported an increase in “standard sickness rating”, as symptom onset time.

[a] During a screening session, potential participants who did not appear to be susceptible to VIMS were excluded.

[b] The order of testing was balanced across the female participants, to minimize the influence of any primacy or recency effects.

[c] For female participants, the cycle is their menstrual cycle, and then, those four days fall in line with peaks and troughs of ovarian hormone levels. For the participants in OC group, day 5 corresponded to day 5 of their “pill-free” week.

6.4.4 Age

6.4.4.1 Key aspect

Effects of age: the effect of age has not been made clear because of the shortage of the studies in the field, either on younger people or on elder people. The effect should be further examined.

The literature has often cited the effects of age obtained mainly from seasickness and airsickness (e.g. Reason and Brand, 1975), which showed that infants below 2 years old are not susceptible to motion sickness, while the susceptibility becomes larger from 2 to 12 years old. Then, the susceptibility decreased largely between 12 and 21 years old; its decline continues and almost disappears beyond the age of 50. The effect of age may be related not only to development of physiological and psychological conditions but also to physical and social environment. Therefore, the effect should be further examined carefully.

6.4.5 Active/Passive viewing

6.4.5.1 Key aspect

Different effects of active and passive viewing: incidence of VIMS is smaller for actively viewing the images than for passively viewing.

NOTE Active viewing represents watching and simultaneously manipulating moving images interactively, while passive viewing represents watching moving images without any active control. One example of active viewing is driving a virtual car in a driving simulator.

6.4.5.2 Description

A between-participants, yoked control design was used with individual “passengers” being yoked to individual “drivers” by Dong et al. (2011). Each of the drivers played a driving video game for up to 40 min, while the recording of that performance was viewed by each passenger paired with the driver. After the experimental trial, or at the time of dropping out the trial, the participants were asked whether they were motion sick. The rate of motion sickness was significantly larger for the passenger's group than for the driver's group.

6.4.5.3 Applications

This factor may be useful for considering the effects of active/passive viewing on VIMS, especially for considering types of usage of moving images to reduce the incidence of VIMS from the images.

6.4.5.4 Constraints

The effect of age was examined using a driving video game. The other types of interactive moving images should be examined.

6.4.5.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 33.

Table 33 — Methods used in the factor — Active/Passive viewing

	Dong X, Yoshida K, Stoffregen TA (2011)
Participants	26 (15 females, 11 males; age average, 23 ± 7,6; Height 1,70 ± 0,08 m)
Display device	A plasma flat screen display
Display content	The driver’s-eye view of a driving simulator game, “Forza Motosport 2”. There were no other cars on the road.
Display resolution	Not specified
Display size	60° × 48° (1,65 m diagonal)
Viewing distance	1,0 m (deduced from the display size, while the literature mentioned, “The stool was 1,8 m from the screen.”)
Chin/head-rest	None
Fixation	None
Viewing period	40 min
Experiment conditions	There were two conditions: (a) Drivers: playing a driving video game, (b) Passengers: watching a recorded image of the driving performance of the paired driver.
Experimental design	Between subject design

Table 33 *(continued)*

	Dong X, Yoshida K, Stoffregen TA (2011)
Physiological measurements	None
Psychological measurements	Before/after the experimental trial: SSQ, After the experimental trial: a self-report of motion sickness (yes/no), movement of head and torso.

6.4.6 Fixation

6.4.6.1 Key aspect

Effects of fixation on VIMS severity: incidence of VIMS is smaller during eyes' fixation on a stationary point superimposed on a moving image than during eyes' free viewing.

6.4.6.2 Description

Stern et al. (1990) exposed participants to visual yaw rotation produced by an optokinetic drum for 12 min in three conditions: (i) the control condition (full visual field without fixation point), (ii) the restricted field condition (restricted visual field without fixation point), and (iii) the fixation condition (full visual field with fixation point). The averaged symptom scores based on Graybiel's scale obtained every 2 min showed significant main effect for conditions; the control condition was significantly larger than either of the other conditions (Figure 2 in Stern et al., 1990).

Webb and Griffin (2002) exposed participants to visual yaw rotation produced by an HMD for 30 min in two conditions: (i) the normal condition (without fixation point) and (ii) the fixation condition (with fixation point). The scores of a 7-point motion sickness scale obtained every 30 s (Figure 4 in Webb and Griffin, 2002) were analysed as averaged accumulated values over 30 min in each condition; the value in the fixation condition was significantly smaller than that in the condition without fixation point.

Bonato et al. (2015) exposed participants to visual yaw rotation produced by an optokinetic drum for 5 min in two conditions: (i) the control condition, in which no fixation point was presented on a see-through display worn by participants, and (ii) the experimental condition, in which fixation point was presented as a cross of Cartesian axes on the see-through display. Averaged SSQ scores were significantly smaller in the experimental condition than in the control condition (Figure 4 in Bonato et al., 2015).

6.4.6.3 Applications

This factor may be useful for considering the effects of presenting fixation point, which is stationary to the display surface, on reducing severity of VIMS.

6.4.6.4 Constraints

The effect was examined using visual yaw rotation. The other types of visual motion should be examined.

6.4.6.5 Experimental methods

The methods used in the experiment cited in this factor are shown in Table 34.

Table 34 — Methods used in the factor — Fixation

	(i) Stern RM, Hu Senqi, Anderson RB, Leibowitz HW, and Koch KL (1990)	(ii) Webb NA and Griffin MJ (2002), Exp.2	(iii) Bonato F, Bubka A, and Krueger WO (2015)
Participants	45 (22 females, 23 males; students in an introductory psychology course)	18 participants	14 (10 females, 4 males; age average, 23,1 years)
Display device	A circular vection drum	An HMD (Virtual Research, VR4)	An optokinetic drum (diameter 107 cm, height 122 cm)
Display content	Not specified except drum rotation speed of 60°/s	Simulated yaw rotation of an optokinetic drum, of which speed was 30°/s	a black and white checkerboard pattern, each of which patch was 9° (height) × 30° (width) inside the drum
Display resolution	N/A; real object	(247 × 230) pixels, 60 Hz	N/A; real objects
Display size	Whole visual field in the control condition and in the fixation condition, and restricted circular visual field of 15° with goggles in the restricted field condition	(48 × 36) °	No specific value; the visual stimulus was viewed through a see-through display (AdviTech X-MotionTM)
Viewing distance	35 cm	Not specified, except the focal distance as 1,0 m	48,5 cm
Chin/head-rest	Chinrest	The heads of participants were restrained using a strap attached to the display	Chinrest
Fixation	A 1 cm black cross in the fixation condition, but No fixation point in the control condition and in the restricted field condition	None in the normal condition, and a stationary cross in the fixation condition	None in the control condition, and a fixation point presented as a cross of Cartesian axes on the see-through display
Viewing period	12 min for drum rotation (total 36 min; 12 min each for baseline, drum rotation, and recovery periods)	30 min	5 min
Experiment conditions	There were three conditions: (a) The control condition: an unobstructed full visual field without fixation point, (b) The restricted field condition: a visual field restricted to 15° circular field by goggles, (c) The fixation condition: a 1 cm black cross was presented as a fixation point, which is 25 cm in front of the eyes and 10 cm from the surface of the drum.	There were two conditions: (a) The normal condition: the optokinetic stimulus without fixation, (b) The fixation condition: the same stimulus with a superimposed stationary cross.	There were two conditions: (a) The control condition: a see-through display on which a cross of Cartesian axes were not presented, (b) The experimental condition: a see-through display on which a cross of Cartesian axes are presented.
Experimental design	Between subject design	Within subject design	Between subject design

Table 34 *(continued)*

	(i) Stern RM, Hu Senqi, Anderson RB, Leibowitz HW, and Koch KL (1990)	(ii) Webb NA and Griffin MJ (2002), Exp.2	(iii) Bonato F, Bubka A, and Krueger WO (2015)
Physiological measurements	During stimulus period: EGG (Electrogastrogram), respiration, horizontal eye movements	None	None
Psychological measurements	Every 2 min during stimulus period: reports of symptoms of motion sickness, which was scored using Graybiel's scale, vection intensity.	Before experiment: visual acuity, motion sickness history questionnaire, During stimulus period: A 7-point motion sickness scale, a 4-point vection scale, eye movement data inspected visually.	Before/after the experimental trial: SSQ, After the experimental trial: overall well-being scale (0: I feel fine, ..., 10: I feel awful as if I am about to vomit), self-motion perception (0: I didn't feel like I was moving at all, ..., 10: I felt like I was rotating and the drum appeared to be totally stationary).

7 Susceptibility probability of motion sickness

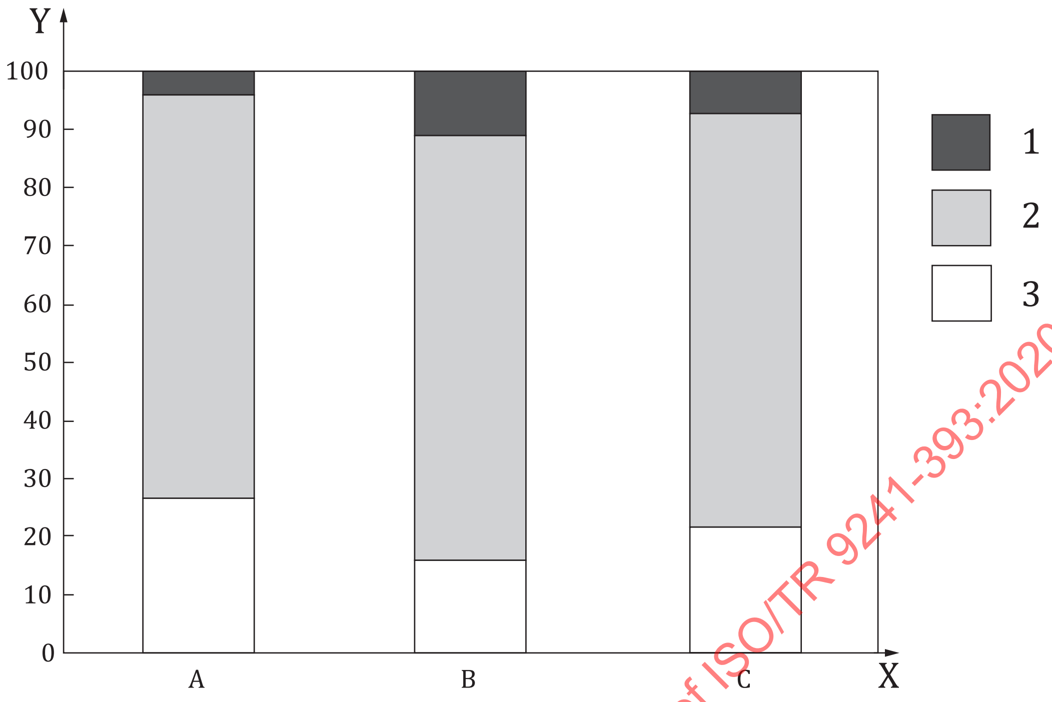
There is insufficient data indicating the distribution of susceptibility to VIMS, but there is sufficient data in regard to susceptibility to MS, which can be a useful reference for susceptibility to VIMS.

Lentz and Collins (1977) conducted research of MS using a questionnaire, which was sent to 3 618 students. Within the questionnaire, they had the students subjectively score 20 different conditions in terms of the extent to which they easily become sick, on a 5-point scale (0 = never sick; 1 = rarely sick; 2 = occasionally sick; 3 = often sick; and 4 = almost always sick). Based on the average score of each individual, they classified the students into three degree-of-susceptibility groups ('unsusceptible', 'moderately susceptible', 'very susceptible'). As a result, 'unsusceptible' accounted for 22 %, 'moderately susceptible' 71 %, and 'very susceptible' 7 %. The histogram of the distributions not only of all the students, but also of male and female students is shown in Figure 7.

Birren (1949) conducted research of sea sickness using a questionnaire that was sent to 511 sailors. He found that people answering that they were "almost always" getting sick accounted for 7,0 % (or 36 people) and those "never" getting sick accounted for 37,6 % (192 people).

Kakiuchi et al. (1981a) investigated the distribution of MS susceptibility among 6 861 elementary and junior high school students in Amagasaki-city and Totsukawa village in Japan with a questionnaire of MS. They found that students always getting sick accounted for 7,7 % (530 students) and those never getting sick accounted for 35,6 % (2 447 students). Moreover, Hasegawa et al. (1963) conducted research on MS on almost one million (976 602) of elementary, junior high and high school students in the Osaka prefecture in Japan and determined that the students who were always getting sick accounted for 2,5 % (21 461 in 872 075) in elementary and junior high schools and 2,11 % (1 164 in 55 151) in senior high schools. Although they reported that their research on MS was narrowed down to students who were always getting sick, they did not describe how they narrowed it down, which makes comparison with other research difficult. Kakiuchi et al. (1981b) speculated that the reason why the ratio of susceptible people in Hasegawa et al. (1963) is lower than in others reflects a considerable increase in transport facilities, especially an increase in the use of automobiles since the work of Hasegawa et al. (1963).

In summary, these results are almost similar in that very few susceptible people exist (almost 7 % to 8 %), and that more insusceptible people (20 % to 35 %) exist, irrespective of the age or region that was investigated.



Key

X category of gender

Y percent ratio

A male

B female

C All

1 non-susceptible

2 moderately susceptible

3 very susceptible

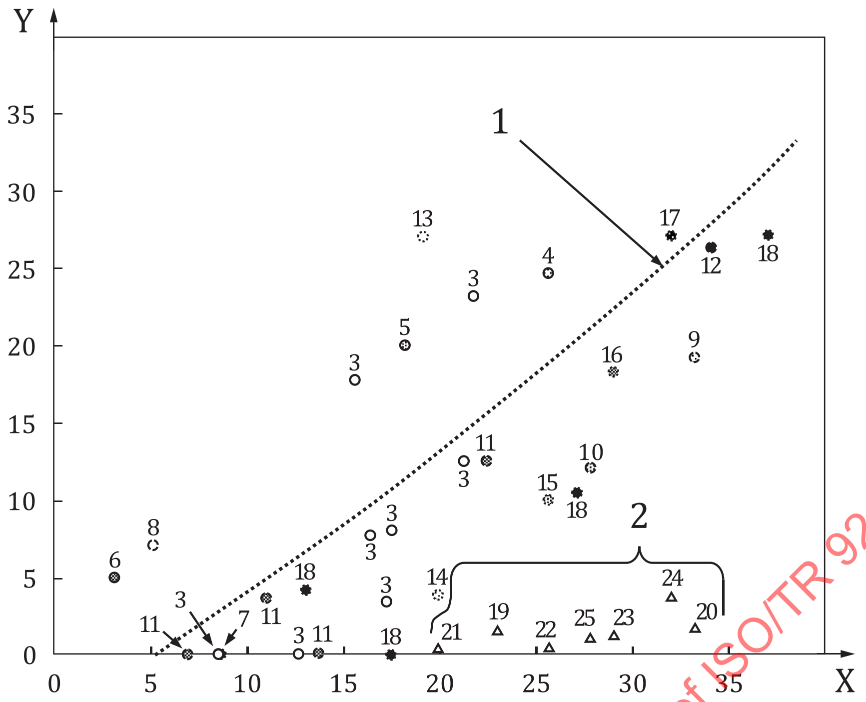
Figure 7 — Distribution of MS susceptibility in Lentz and Collins (1977)

8 Scaling of VIMS severity

In order to consider ergonomic guidelines for reducing incidence of VIMS, it is important to estimate the severity of visually induced motion sickness in various conditions, which will be the basis for determining the required limit and the recommended limit. This consideration can be rather easy if the severity of VIMS in each of the individual condition can be indicated in any concrete manner. To realize this, it is important to quantitatively scale the severity of VIMS by any numerical value.

In the research field of VIMS, SSQ has been often used for evaluating the severity of VIMS. Therefore, it is possible to examine the relationship between the severity of sickness experienced and the SSQ total scores obtained in experiments conducted on VIMS or in simulator trainings. For the severity of sickness, it is possible to use the rate of vomit and the rate of drop-out from those experiments and simulator trainings. In fact, Balk et al. (2013) showed a correlation between SSQ total scores and the rate of drop-out.

Based on the idea above, Figure 8 plots the data reported in the previous literature on SSQ total scores and simultaneously on the rate of drop-out and/or vomit. This figure actually shows that the rate of drop-out increases with the SSQ total scores, and the rate of vomit is 3 % at most around an SSQ total score of 30 or more.



Key

X averaged SSQ-TS

Y dropout rate (%)

1 fitted line to “drop-out” rate data (3 to 18):

$Y = 0{,}005\ 7X^2 + 0{,}744X - 3{,}973\ 9$, $R^2 = 0{,}352\ 4$

2 data of “vomit” rate

3 Balk et al. (2013)

4 Reed et al. (2007) Exp.1

5 Reed et al. (2007) Exp.2 Cont.

6 Reed et al. (2007) Exp.2 S

7 Reed et al. (2007) Exp.2 F

8 Reed et al. (2007) Exp.2 S+F

9 Stanney et al. (1999)

10 Stanney et al. (2002)

11 Ujike et al. (2005)

12 Koslucher et al. (2015)

13 Park et al. (2006)

14 Stanney et al. (2003) after 15 min

15 Stanney et al. (2003) after 30 min

16 Stanney et al. (2003) after 45 min

17 Stanney et al. (2003) after 60 min

18 Ujike and Watanabe (2017)

19 Kingdon et al. (2001) vomit

20 Stanney et al. (1999) vomit

21 Stanney et al. (2003) vomit 15 min

22 Stanney et al. (2003) vomit 30 min

23 Stanney et al. (2003) vomit 45 min

24 Stanney et al. (2003) vomit 60 min

25 Stanney et al. (2002) vomit

Figure 8 — Distribution of “drop-out” rate and “vomit” rate as a function of averaged SSQ total score from literatures on VIMS and simulator sickness

Values of SSQ total score have been categorized in six levels corresponding to the severity of symptoms by Kennedy et al. (2001) (Table 35). According to this categorization, a score of less than 5 is “negligible”, while the scores from 10 to 20 become “significant” and “a concern”. Figure 8 seems to correspond to this categorization. The fitted line to the drop-out rate rises from zero at an SSQ total score of 5, and then goes over 10 % for the score between 10 and 20, while the vomit rate rises from zero at an SSQ total score of 20.

Therefore, in order to consider ergonomic guidelines for reducing the incidence of VIMS, it is useful to use SSQ total score as an index of severity of VIMS (see Annex B) as the basis for determining the required limit and the recommended limit.

Table 35 — Categorization of symptoms for SSQ TS

SSQ score	Categorization
0	No symptoms
<5	Negligible symptoms
5–10	Minimal symptoms
10–15	Significant symptoms
15–20	Symptoms are a concern
>20	A problem simulator

9 Summary

Image safety, including VIMS, is now more important, when the role of video images serving society has become increasingly important. Although image safety is naturally important, the ambitious production and use of moving images should preferably not be fully restrained. The issue can be addressed by advancing moving image technology based on an understanding of the characteristics of VIMS.

One important method of understanding VIMS is to accumulate scientific knowledge, and also to standardize ergonomic guideline based on the scientific knowledge. With our eyes set on international standardization for reducing the incidence of VIMS, this document attempts to summarize the scientific knowledge of VIMS by way of presenting an effective procedure for developing an advanced understanding of VIMS.

The scientific knowledge is summarized in 6.2 to 6.4, which is classified in three categories: visual image factors, visual environmental factors, and individual viewer factors. For understanding well these scientific findings, the factors are described from the viewpoints of main effects, ergonomic applications, and constraints. Also, the methods and results were described of those experiments as cited.

Moreover, the idea of scaling severity of VIMS is described in Clause 8 in terms of SSQ total score. The scaling is important to consider ergonomic guidelines for reducing incidence of VIMS, especially when determining the required limit and the recommended limit.

Furthermore, to view the scientific knowledge from the point of empirical knowledge, the relation between these two types of knowledge are described in Annex C, which can be easier to understand for people involved in image production.

Based on the scientific knowledge described in this document, the discussions can be promoted to develop International Standard for reducing VIMS.

Annex A
(informative)

Overview of the ISO 9241 series

Table A.1 presents an overview of the structure of the ISO 9241 series.

The structure reflects the numbering of the original ISO 9241 standard; for example, displays were originally ISO 9241-3 and are now the ISO 9241-300 series. In each section, the "hundred" is an introduction to the section; for example, ISO/TR 9241-100 gives an introduction to the software-ergonomics parts.

Table A.1 — Structure of the ISO 9241 series, *Ergonomics of human–system interaction*

Part	Title
1	Introduction
2	Guidance on task requirements
11	Usability: Definitions and concepts
20	Accessibility guidelines for information/communication technology (ICT) equipment and services
21–99	To be assigned
100	Software ergonomics
200	Human–system interaction processes
300	Displays and display-related hardware
400	Physical input devices — Ergonomics principles
500	Workplace ergonomics
600	Environment ergonomics
700	Special application domains
800	To be assigned
900	Tactile and haptic interactions