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Ergonomics of human-system interaction —

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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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

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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.

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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

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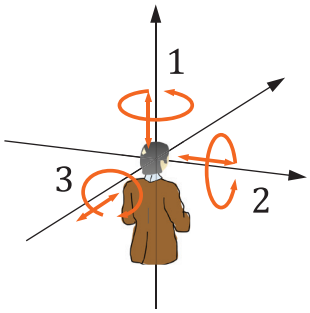
3.5
disorientation
loss of sense of direction, position or relationship with the surroundings

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.

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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

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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.

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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.

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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	+	+	+	+

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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).

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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

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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.	

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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.

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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.

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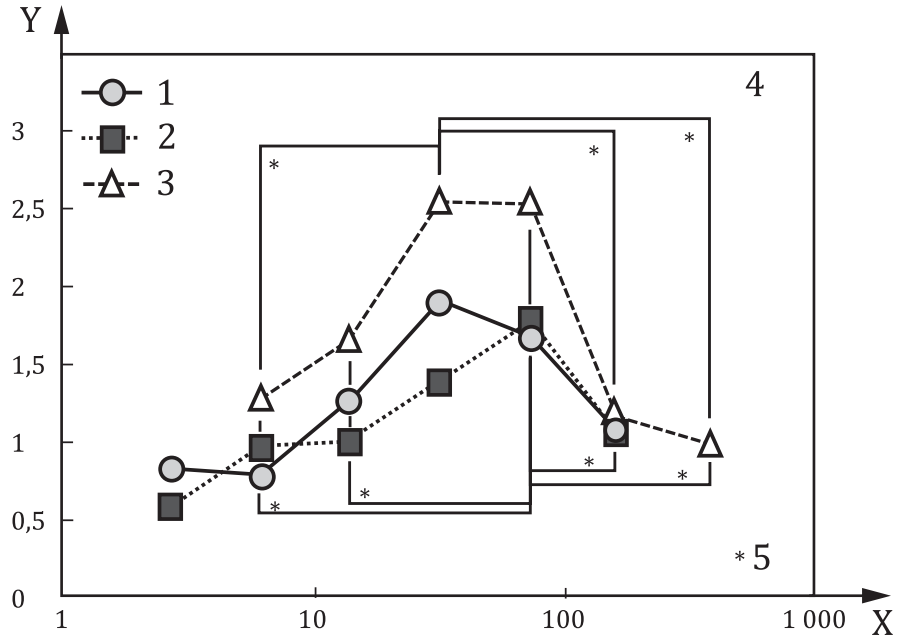
6.2.4.2 Description



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.

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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

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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.

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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.

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Table 9 *(continued)*

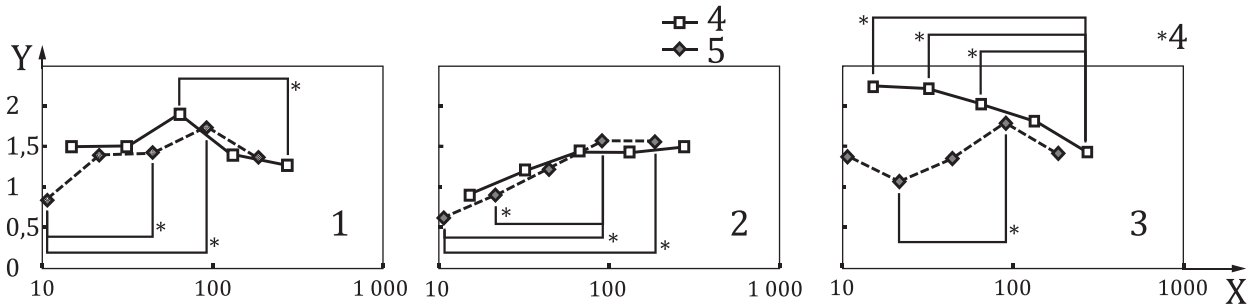
Psychological measurements	Every 2 min during stimulus period: symptoms of MS (SSMS)	Before/after stimulus period: SSQ	Before/after stimulus period: SSQ, self-motion perception
[a] Rate of the expansion was consistent with an optic flow produced with a speed of 340 km/h with a visible range of 220 m.			

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.

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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.

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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

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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).

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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.

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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.

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