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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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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

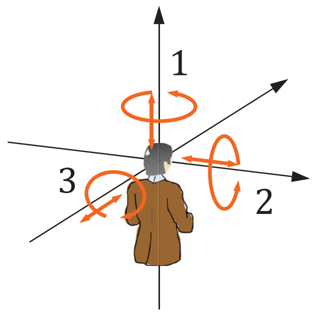
3.3
vertigo
sensation of rotation or movement of oneself (subjective vertigo), or of rotation or movement of one's surroundings (objective vertigo), in any plane, caused by diseases of the inner ear, or by disturbances of the vestibular centres or pathways in the central nervous system

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.