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Ergonomics of human-system interaction —

Part 394: Ergonomic requirements for reducing undesirable biomedical effects of visually induced motion sickness during watching electronic images

Ergonomie de l'interaction homme-système —

Partie 394: Exigences ergonomiques pour la réduction des effets biomédicaux indésirables des cinétoses induites par stimulus visuel lors de l'observation d'images électroniques

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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).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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, *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.

Introduction

With the advancement in image technologies, it is now possible to experience various new types of images through different kinds of electronic displays, for example, ultra-high definition (UHD) images and virtual reality images. These technologies make our daily lives more convenient and enable different lifestyles.

The new products of advanced image technologies can be popularized both by solving technical issues and by devising countermeasures for reducing incidences of undesirable biomedical effects, such as visually induced motion sickness.

This document describes the basic and minimal conditions for reducing incidences of visually induced motion sickness. It is intended to promote an environment in which viewers can enjoy the benefits of images without the adverse effects of visually induced motion sickness. In such an environment, new technologies for images can also be actively developed and applied in various fields. This document is not intended to restrict the freedom of expression or artistic creativity in the image culture.

This document is based on scientific findings related to the possible undesirable effects of visually induced motion sickness. In the future, this document could be revised as new scientific data become available.

This document is part of the ISO 9241 series, which specifies human–system interaction standards. Readers who need guidance on other aspects of human–system interaction can therefore refer to other documents in the ISO 9241 series. See Annex A for an overview of the ISO 9241 series.

Ergonomics of human-system interaction —

Part 394: Ergonomic requirements for reducing undesirable biomedical effects of visually induced motion sickness during watching electronic images

1 Scope

This document establishes the requirements and recommendations for image contents and electronic display systems to reduce visually induced motion sickness (VIMS), while viewing images on electronic displays.

This document is applicable to electronic display systems, including flat panel displays, projectors with a screen, and virtual reality (VR) type of head mounted displays (HMDs), but not including HMDs that present electronic images on/with real-world scenes.

NOTE 1 This document assumes the images are viewed under appropriate defined conditions. See Annex B for the appropriate viewing conditions.

NOTE 2 This document is useful for the design, development, and supply of image contents, as well as electronic displays for reducing VIMS.

NOTE 3 ISO 9241-392[3] provides guidelines for stereoscopic 3D displays, of which the methods are also used in HMDs.

NOTE 4 The International Telecommunication Union (ITU) generally sets the standards for broadcasting.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9241-302 and the following 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 can include dizziness, vertigo, 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 one's self (subjective vertigo), or of rotation or movement of one's surroundings (objective vertigo), in any plane

3.4
postural instability
set of conditions in which voluntary movements cannot be well coordinated for maintaining posture

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

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

Note 1 to entry: There are generally six types of visual global motions that correspond to the different types of motions of a camera during the capturing of images: rotation around and translation along the pitch, yaw, and roll axes.

3.7
head-mounted display
HMD
display device that is worn on the head, is integrated into eyeglasses, or is built in as part of a helmet or a hat

3.8
virtual reality
VR
set of artificial conditions created by computer and dedicated electronic devices that simulate visual images and possibly other sensory information of a user's surrounding with which the user is allowed to interact

Note 1 to entry: The artificial conditions do not reflect a user's real-time physical environment.

4 Guiding concepts

4.1 Contexts of image viewing

Two different viewing environments are defined for the contexts of image viewing to reduce VIMS. One is the active viewing environment, in which either the motion, orientation or other displayed contents of the images vary according to any viewers' actions, such as head movements or the manipulation of controllers. The other is the passive viewing environment, in which any displayed contents of the images do not vary with viewers' actions. In the active viewing environment, the changes in the displayed contents are caused by tracking the head of the viewers, or by the viewers operating the controller. In this document, the contexts of image viewing in the two viewing environments are the following:

— passive viewing environment:

  — display device: flat panel display, projector, or head-mounted display;

  — image generation: real-time rendering or playing recorded images;

  — image size in visual angle: depending on applications and display device;

  - interactive type: none;
- active viewing environment:
  - display device: flat panel display, projector, or head-mounted display;
  - image generation: real-time rendering;
  - image size in visual angle: depending on applications and display device;
  - interactive type: head tracking and/or controller.

4.2 Basis of guiding concepts

This document provides the basic and minimal conditions for reducing incidences of VIMS primarily from the viewpoint of nauseating symptoms, such as dizziness, sweating, headache, stomach awareness, nausea, and vomiting. In this subclause, the references are verified as the bases for the guidelines from literature and summaries, and also from their reported scores from the simulator sickness questionnaire (SSQ).

Nauseating symptoms are reflected in the drop-out rates in various experiments of VIMS and simulator training. The relationship between drop-out rates and SSQ total score (SSQ-TS) has been clarified[4]. The drop-out rates were also reported to be correlated with the nausea subscore of SSQ (SSQ-N)[4]. The conditions for reducing VIMS can be considered in terms of lowering SSQ-TS (and/or the SSQ-N) to some extent. In fact, the severity index of VIMS described in C.4 is based on SSQ-TS.

Meanwhile, another aspect related to VIMS has been reported in the literature, i.e. disorientation induced after exposures to VR. Disorientation is different from nauseating symptoms in that it affects the equilibrium of the body. While postural fluctuation during exposure to VR is an adverse effect from the viewpoint of physical safety during a VR experience, disorientation after exposure to VR is paramount to be considered as an after-effect from the viewpoint of physical safety after returning to the real environment. The disorientation after exposures to VR can be reflected by the disorientation subscore of SSQ (SSQ-D)[5].

The different characteristics of the nauseating symptoms and disorientation after exposures to VR are also to be considered in terms of temporal courses. When viewers are repetitively exposed to the environments that easily induce VIMS, nauseating symptoms are known to be reduced significantly by the habituation to the environments. Moreover, when viewers are repetitively exposed to virtual environments, disorientation occurring every time after the viewers return to the real environment has been reported to increase. In other words, postural fluctuations increase. Consequently, it is paramount to consider this type of undesirable effect, i.e. disorientation, as well as nauseating symptoms. To reduce disorientation, general methods described in D.1 and D.2 can be useful as countermeasures.

4.3 Major factors of VIMS

VIMS is known to be affected by various factors. Among them, the major factor is visual motion within images. It can be either enhanced or attenuated by visual image factors, visual environmental factors, and individual viewer factors.

VIMS can be reduced, to some extent, by considering other major factors such as those shown below, depending on the context of image viewing. Therefore, to control VIMS, those different major factors need to be simultaneously considered with an appropriate balance.

Passive viewing environment:

- amount of visual global rotation:
  - different types of visual global rotations;
  - velocity of visual global rotation;

  - viewing period;
- image size in visual field;
- fixation-point/visual-target;
- navigating velocity;
- predictive information of self-motion;
- independent background from visual motion.

Active viewing environment:

- amount of visual global rotation;
  - different types of visual global rotations;
  - velocity of visual global rotation;
  - viewing period;
- image size in visual field;
- fixation-point/visual-target;
- navigating velocity;
- predictive information of self-motion;
- independent background from visual motion;

  (for the environment especially by head tracking)
- match in visual field between virtual camera and display (especially for large visual field images or VR type of HMD);
- match of head motion and visual motion (especially for large visual field images or VR type of HMD);
- delay in head tracking.

5 Ergonomic requirements and recommendations

5.1 General

To obtain the condition that sufficiently reduces the possibility of VIMS, visual image factors, visual environmental factors, and individual viewer factors shall be considered. However, in this document, the following are of principal concern:

- visual image factors, such as velocity and types of visual global motion and viewing period; and
- visual environmental factors, such as image size in visual field, fixation-point/visual-target, luminance level of images, illuminance level of environment, image resolution, and delay of head tracking.

For individual viewer factors, information can be found in Annex G.

NOTE The principles in 5.2 are easier to apply in the case of pre-recorded contents, which can be analysed frame by frame. Interactive media, such as video games, can afford essentially limitless sequences throughout the game, depending on the user's actions. In the case of video games, the requirements and recommendations apply to typical sequences of play but cannot cover every eventuality of play.

5.2 Images presented in passive viewing environments

5.2.1 Potentially unwanted conditions of visual rotation

Potentially unwanted conditions of visual rotation shall be avoided.

Potentially unwanted conditions of visual rotation are defined as those satisfying any of the following conditions.

a) Total amount of yaw rotation within a 20-minute period at any time of images is more than 17 280° (or 48 rounds).

b) Total amount of pitch rotation within a 20-minute period at any time of images is more than 15 120° (or 42 rounds).

c) Total amount of roll rotation within a 20-minute period at any time of images is more than 14 400° (or 40 rounds).

NOTE The criterion values above are applied while the image size in visual field is assumed as in the range of 30° × 17° to 70° × 40°.

5.2.2 Potentially unfavourable conditions of visual rotation

Potentially unfavourable conditions of visual rotation should be avoided.

Potentially unfavourable conditions of visual rotation are defined as those satisfying any of the following conditions.

a) Total amount of yaw rotation within a 20-minute period at any time of images is more than 12 960° (or 36 rounds).

b) Total amount of pitch rotation within a 20-minute period at any time of images is more than 11 520° (or 32 rounds).

c) Total amount of roll rotation within a 20-minute period at any time of images is more than 10 800° (or 30 rounds).

NOTE 1 The criterion values above are applied while the image size in visual field is assumed to be 30° × 17° or larger.

NOTE 2 Visual images can be enlarged in certain use cases, such as in the medical field. In such cases, the amount of rotation can be underestimated, if it is obtained by the actual camera rotation.

5.2.3 Basis of the requirements and recommendations

In 5.2.1, 5.2.2 and 5.3.2, the numerical criteria were set based on the relation between the dropout rate and total amount of rotation presented in the images on electronic displays in the experiments of VIMS[6]. In this process, the dropout rate was obtained by transforming the experimentally obtained SSQ-TS using Formula (1) (see Figure C.1):

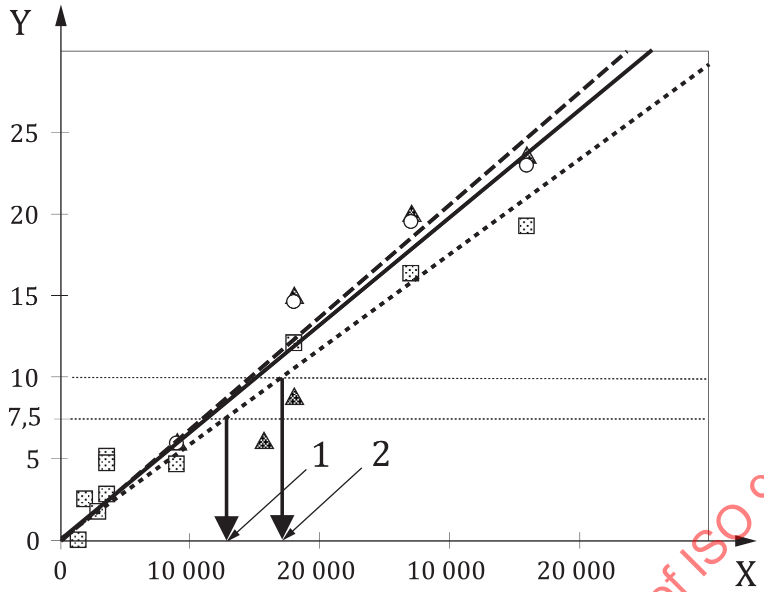
$$Y = 0{,}0057X^2 + 0{,}744X - 3{,}973\ 9,\ R^2 = 0{,}352\ 4 \quad (1)$$

where

X is the averaged SSQ-TS;

Y is the dropout rate (%).

Those relations between dropout rate and total amount of rotation are shown in Figure 1, with fitted linear lines for each data of pitch, roll, and yaw-axes rotations. As shown in the graph, the criteria for the requirements are set in terms of 10 % of the dropout rate, while those for the recommendations are set in terms of 7,5 % of the dropout rate.



Key

X total amount of rotation around a single axis within 20 min (°)

Y dropout rate (%)

⊠ .... yaw

▲ ——— pitch

○ – – – – roll

1 criterion for recommendation of yaw

2 criterion for requirement of yaw

Figure 1 — Relation between dropout rate and total amount of rotation around each of three axes

5.2.4 Reference information on effects of visual motion combination

For considering the effects of visual motion combination, see C.3.

5.3 Images presented in active viewing environments

5.3.1 General

For images in the active viewing environments, the major factors to be considered are those of visual motion described in 5.2 as well as those specific to these environments, such as:

— the time delay of changing images yoked to the signals from the head tracking or controllers;

— the consistency of visual field between virtual camera and presented images especially for large visual field images or VR-type HMDs with head tracking system; and

— the consistency of direction and amount of head movements with image motion.

5.3.2 Potentially unfavourable conditions of visual rotation

Potentially unfavourable conditions of visual rotation, not caused by head movements, should be avoided.

Potentially unfavourable conditions of visual rotation are defined as those satisfying either of the following conditions.

a) Total amount of yaw rotation within a 20-minute period at any time of images are more than 17 280° (or 48 rounds).

b) Total amount of pitch rotation within a 20-minute period at any time of images are more than 15 120° (or 42 rounds).

c) Total amount of roll rotation within a 20-minute period at any time of images are more than 14 400° (or 40 rounds).

Rotations above are not produced by head tracking.

NOTE 1 This document only describes the recommendations for visual rotation in active viewing environments different from the passive viewing environment, which does not necessary indicate that active viewing environments are generally less severe than passive viewing environments.

NOTE 2 The criterion values above are applied while the image size in the visual field is assumed to be 30° × 17° or larger.

NOTE 3 Visual images can be enlarged in certain use cases, such as in the medical field. In such cases, the amount of rotation can be underestimated, if it is obtained by the actual camera rotation.

5.3.3 Reference information on effects of visual motion combinations

For considering the effects of visual motion combination, see C.3.

5.3.4 Potentially unfavourable conditions of large visual field images or VR-type HMDs

Potentially unfavourable conditions of large visual field images or VR-type HMDs should be avoided as follows:

a) the field of view of the virtual camera and that of the images presented are matched as much as reasonably achievable;

b) the direction and speed of the virtual camera motion and those of the user's head motion are matched as much as reasonably achievable.

NOTE 1 For the presentations of stereoscopic 3D images with a wide field view or the VR-type HMDs, refer to ISO 9241-392[3].

NOTE 2 Adjustments in matching the direction and speed of virtual camera motion and those of the user's head motion can be affected by several factors, including the static/dynamic characteristics of detecting the devices in motion in HMDs.

NOTE 3 The time delay in visual image change corresponding to the displayed image of the user's head movements can affect VIMS. A study reported that the primary factor of time delay inducing VIMS was the temporal variability[7]. The sample measurement method is described in Annex F.

6 Conformance and usages of ergonomic recommendations

6.1 General

For developing image contents and electronic displays, this document provides the ergonomic requirements and recommendations for reducing VIMS.

To comply with the requirements in Clause 5, the procedure described in 6.3 should be followed using the evaluation methods described in 6.2.

To follow the recommendations in Clause 5, the procedure described in 6.3 can be followed using the evaluation methods described in 6.2.

6.2 Measurement methods

To evaluate electronic visual images according to the items described in 5.2.1, 5.2.2, and 5.3.2, the measurement of pixelated video signals transmitted to electronic visual displays is essential. The measurement method is described in Annex E.

6.3 Procedure of conformance and report

Conformance with this document is achieved by satisfying all the applicable requirements. For the recommendations provided in this document, the evaluations of products can be reported. For reference purposes, the clauses including the requirements and those including the recommendations are listed in G.2. Users of this document shall evaluate the applicability of each requirement and should evaluate the applicability of each recommendation. If a product is claimed to have met the applicable items in the requirements, the procedure used in evaluating the product shall be specified. If a product is claimed to have met the applicable items in the recommendations, the procedure used in evaluating the product should be specified.

Annex G provides an example of both determining and recording the applicability of all the requirements and recommendations in Clause 5, and for reporting that they have been evaluated. Other equivalent forms of report are acceptable.

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

Annex B
(informative)

Viewing conditions

B.1 General

To reduce the potential for VIMS while viewing moving images, the appropriate viewing conditions are important. It is useful for the providers of image content, electronic displays, and final products of image presentation to inform the viewers of the following information regarding the viewing conditions.

B.2 Setting viewing position and posture

It is generally assumed that moving images are viewed with a certain viewing distance from the electronic display surface. If the viewing distance is shorter than is assumed, visual fatigue can be enhanced, which can affect the severity of VIMS. Moreover, shorter viewing distances generally lead to larger image sizes of the visual field, which is known to possibly enhance VIMS[8][9][10].

For high-definition images with an aspect ratio of 16:9, the viewing distance is recommended as triple the height of the display area (3H, or 3× height[2]), or as the range of triple to six-fold the height of the display area[11]. The viewing distance is one of the factors determining the visual field size of moving images. Regardless of the viewing distance, it is useful for viewers to be informed of the assumed viewing distance.

B.3 Confirmation of clear and appropriate visual images

While viewing stereoscopic images, if the viewer experiences double-vision or does not experience stereopsis, it is appropriate that the viewer stops viewing the images and verifies the settings of the stereoscopic image content, stereoscopic display, and viewing conditions. If the viewer experiences discomfort while watching stereoscopic images, pseudostereopsis can have occurred, in which the left and right images are reversed, thus resulting in reversed binocular parallax. If the viewer realizes that pseudostereopsis has occurred, it is advisable to remove the cause of the pseudostereopsis or to stop viewing the stereoscopic images.

Individual differences exist in how people experience stereopsis, visual fatigue, discomfort, and VIMS when viewing stereoscopic images. If the viewer does not experience stereopsis or feels discomfort even while viewing appropriately adjusted stereoscopic images and displays, it is advisable to stop viewing the stereoscopic images.

B.4 Viewing period

Even when the conditions described in C.2 and C.3 are considered, a long period of image viewing can induce visual fatigue and discomfort, which can affect the severity of VIMS. If the viewer experiences visual fatigue, discomfort, or VIMS (typical symptoms are dizziness, vertigo, sweating, odd feelings in the stomach, and nausea) while viewing the images, a break is advised.

Annex C
(informative)

Effects of visual motion combination

C.1 General

Images generally distributed as consumer products typically include various combinations of visual motions, which have six degrees of freedom, indicating that those visual motions can be disintegrated into the rotation around and the translation along the yaw, pitch, and roll axes. In 5.2 and 5.3, the requirements and recommendations establish the numerical criteria in terms of a single-axis rotation. For readers who are interested in considering the undesirable effects (on VIMS) of the visual motion combination, the severity index of VIMS described in C.4 is useful.

The index is more informative, as shown in C.2 and C.3, because it describes the background and rationale of the severity index of VIMS. Clause C.2 is also useful to understand the basis of the requirements and recommendations described in 5.2.1, 5.2.2, and 5.3.2, in terms of how the dropout rate is determined.

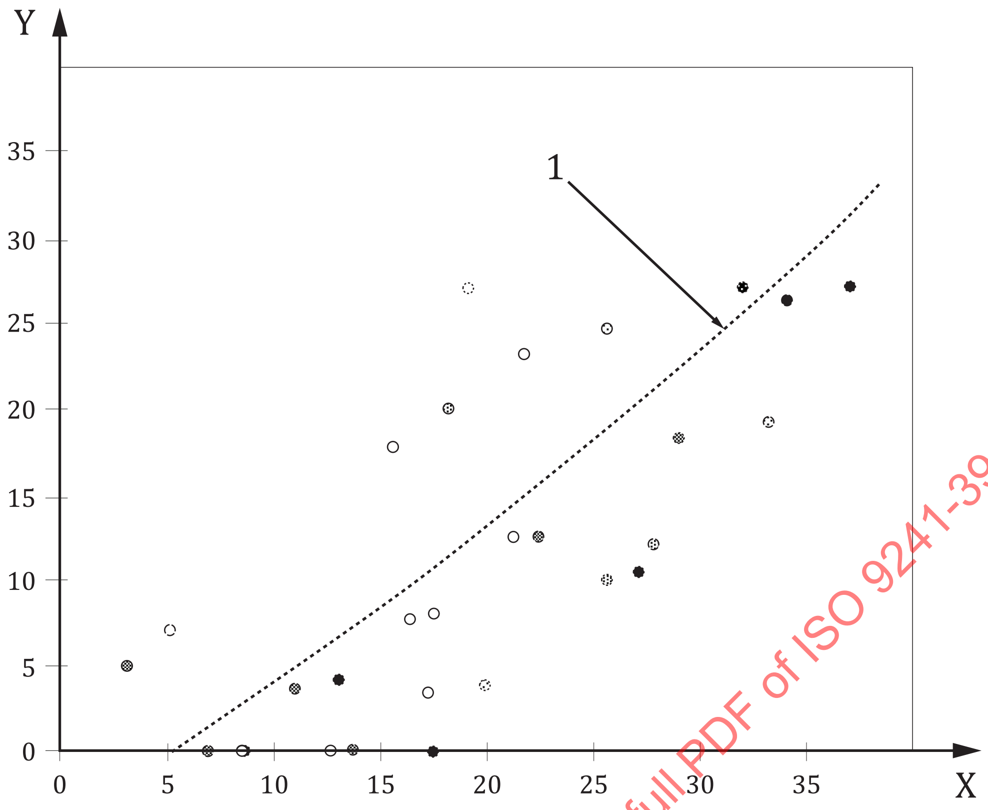
C.2 Dropout rate and SSQ total score

To consider the ergonomic guidelines for reducing incidences of VIMS, it is important to estimate the severity of VIMS in a given condition. To estimate the severity of VIMS symptoms quantitatively, the “severity index” is introduced. This is performed in two steps:

a) determining the scaling of VIMS; and

b) determining an index that relates VIMS severity to the scaling.

VIMS scaling may be realized by a score obtained using the SSQ[12], typically conducted before/after exposures to moving images. In fact, SSQ has often been used for evaluating the severity of VIMS, although it was originally developed for evaluating simulator sickness. Balk et al.[4] reported that the total score of SSQ obtained in his experiments correlated with the rate of dropout. Figure C.1 plots the data shown in the literature reporting both SSQ total scores and the corresponding dropout rates. In the graph, the fitted line to the data is also plotted, with which the dropout rate can be estimated from the SSQ total score.



Key

X averaged SSQ-TS

Y dropout rate (%)

1 $Y = 0{,}0057X^2 + 0{,}744X - 3{,}973\,9$, $R^2 = 0{,}352\,4$

- Balk et al. (2013)
- Reed et al. (2007) Exp.1
- Reed et al. (2007) Exp.2 Cont.
- Reed et al. (2007) Exp.2 S
- Reed et al. (2007) Exp.2 F
- Reed et al. (2007) Exp.2 S+F
- Stanney et al. (1999)
- Stanney et al. (2002)
- Ujike et al. (2005)
- Koslucher et al. (2015)
- Park et al. (2006)
- Stanney et al. (2003) after 15 min
- Stanney et al. (2003) after 30 min
- Stanney et al. (2003) after 45 min
- Stanney et al. (2003) after 60 min
- Ujike and Watanabe (2017)

Figure C.1 — Relation of averaged SSQ total score and dropout rate

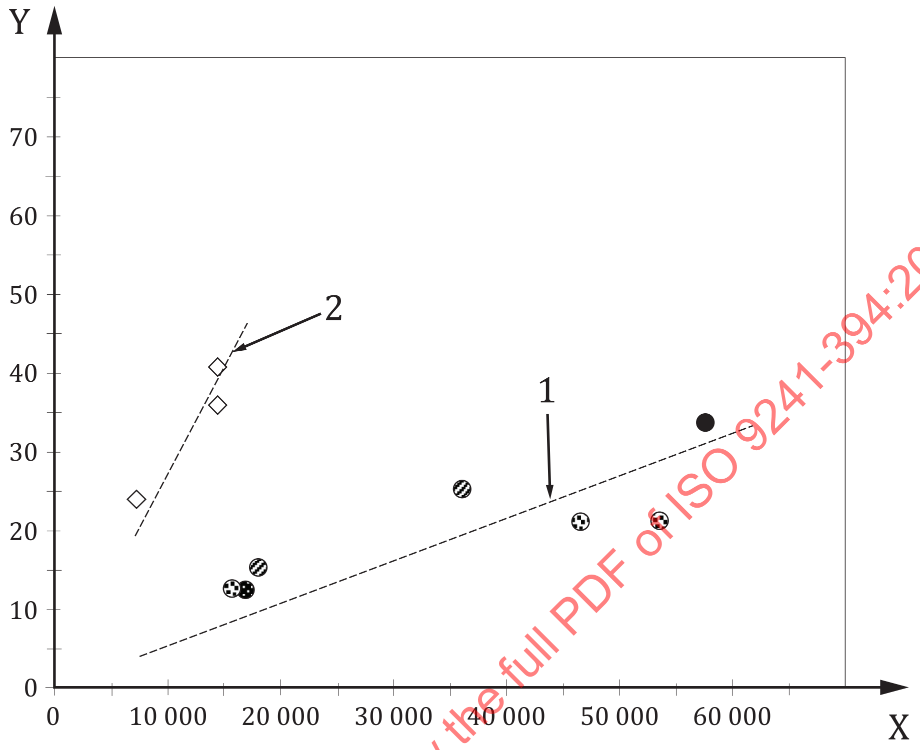
C.3 SSQ total score and total amount of visual rotation around yaw, pitch, and roll axes

A linear relation is shown between the total amount of visual rotation and SSQ total score, as shown in Figure C.2. In the figure, two independent lines are fitted. One line has a relatively gentle slope for the data obtained with images on electronic displays, and the other has a relatively steep slope for the data obtained with a cylindrical drum. The two lines indicate that the SSQ total scores tend to increase linearly as a function of the summation values of visual motion presented with the size in the visual angle from 34° × 26° to 65° × 59°. Meanwhile, for the visual motion presented with an optokinetic drum, the same type of linear function can be obtained, except that the slope is steep. This can indicate the two factors of VIMS severity:

1) the effect of visual rotation; and

2) the effect of viewing environments.

This idea is similar to the motion sickness dose value (MSDV) that is calculated as the temporal integration of frequency-weighted acceleration[1].



Key

X total amount of visual rotation (°)

Y SSQ-TS

1 fitted line for images on electronic displays; stimulus size: 34° × 26° to 65° × 59°

2 fitted line for images with cylindrical drum; stimulus size: full visual field

◇ Bubka et al. (2006)

Bonato et al. (2009)

● Diels and Howarth (2011)

Keshavarz and Hecht (2011)

Ujike et al. (2005)

Figure C.2 — Relation of averaged SSQ total score and total amount of visual rotation

C.4 Severity Index of VIMS

The severity index of VIMS, I_S, is defined as Formula (C.1):

$$I_S = k_1 \cdot k_2 \cdot VM_T \qquad \text{(C.1)}$$

where

k_1 is the coefficient of image size in visual field, defined in D.3;

k_2 is the coefficient of existence of fixation-point/visual-target, defined in D.3;

VM_T is the total dose of visual global rotation.

The total dose of the visual global motion is defined as Formulae (C.1) to (C.5):

$$VM_{\mathrm{T}} = \alpha_{\mathrm{p}} VM_{\mathrm{p}} + \alpha_{\mathrm{y}} VM_{\mathrm{y}} + \alpha_{\mathrm{r}} VM_{\mathrm{r}} \qquad \text{(C.2)}$$

$$VM_{\mathrm{p}} = \sqrt{\int_{t_0}^{t_{\mathrm{p}}} \omega_{\mathrm{p}}^2 (t) dt} \qquad \text{(C.3)}$$

$$VM_{\mathrm{y}} = \sqrt{\int_{t_0}^{t_{\mathrm{p}}} \omega_{\mathrm{y}}^2 (t) dt} \qquad \text{(C.4)}$$

$$VM_{\mathrm{r}} = \sqrt{\int_{t_0}^{t_{\mathrm{p}}} \omega_{\mathrm{r}}^2 (t) dt} \qquad \text{(C.5)}$$

where

ω_{p} is the rotation speed appearing on image screen around pitch axis (°/s);

ω_{y} is the rotation speed appearing on image screen around yaw axis (°/s);

ω_{r} is the rotation speed appearing on image screen around roll axis (°/s);

α_{p} is the weight for rotation speed around pitch axis;

α_{y} is the weight for rotation speed around yaw axis;

α_{r} is the weight for rotation speed around roll axis;

d

t_{p}, t_0 is the ending time and starting time for integration, respectively ($t_p - t_0$ = 1 200 s.);

t is the time (s).

NOTE 1 The values of ω_{p}, ω_{y}, ω_{r} can be those given during image productions, if those are known. Otherwise, those values can be obtained in the analysis method described in Annex E. The values of ω_{p}, ω_{y} and ω_{r} can be consistent with those of the rotation speed of real or virtual cameras capturing the image, if the perspectives of the captured and presented images are consistent.

NOTE 2 The severity index of VIMS is developed based on the relationship between the total score of the (SSQ-TS) and the drop-out rate of the simulator trainings, or of the experimental sessions, which is reported to be correlated with SSQ-N, and thus likely with the severity of undesirable nauseating symptoms. Moreover, as an after-effect of exposures to virtual environments, disorientation, which is the effect on the equilibrium function of the body, is known to appear. Disorientation can be measured by postural fluctuations after exposures to virtual environments, which was reported to be increased from repeated exposures[13]. Therefore, to reduce disorientation, as an after-effect of habituating to virtual environments, the general methods described in D.2 can be useful as countermeasures.

NOTE 3 The severity index of VIMS is still under development. Therefore, it is important to examine carefully the validity of the combination effects of the total amount of visual rotations and viewing conditions as an index of the symptom severity of VIMS.

Annex D
(informative)

General methods of alleviating VIMS

D.1 For users of active viewing and passive viewing environments

It is useful to inform the image viewers regarding VIMS, and to recommend viewing interruptions when viewers experience illness. This information can alleviate anxiety when viewers suffer from VIMS, and can also lead to reduced incidences of VIMS. Moreover, from the viewpoint of securing physical safety from disorientation, it is useful to inform the image viewers about disorientation after exposure to VR. Further, it is useful to set the viewing environments, (e.g., seating, or holding on to a railing), based on considering postural instability when experiencing VR.

D.2 For users of active viewing environments

While nauseating symptoms are mitigated during repetitive exposures to virtual environments having interactivities, disorientation as an after-effect after each exposure is reported to be possibly more severe with repetitive exposures[13][14]. To reduce disorientation, it can be useful to temporally vary the strength of interactivity during exposures to the virtual environment, or to appropriately draw the viewers' attention to the disorientation.

D.3 For active viewing environments by head tracking

VIMS can be alleviated by not providing the visual motion information about the viewers' self-motion other than the visual motion information provided by the tracking system of head movements.

It is useful for image producers to be provided with measurement methods of time delay of the head-tracking system.

D.4 For active viewing and passive viewing environments

When providing visual motion information of viewers’ self-motion, there are several ways to reduce the incidence of VIMS:

1) making visual motion slower;

2) reducing showing visual information of acceleration such as with up-and-down motion or with left-and-right turns;

3) reducing viewers’ perceived self-speed by avoiding thick texture pattern, or by reducing display area of visual motions showing a stationary object relative to the image screen;

4) producing visual information of viewers’ self-motion by their own active movement or control[15];

5) providing predictive information of viewers‘ self-motion direction in the virtual environment[16][17][18];

6) providing a stationary point or an object on the display surface as the viewers‘ fixation point[19][20][21];

7) providing a background surface as if the surface is fixed to the real-world environment[22].

Moreover, providing pleasant music[23] or pleasant odour[24] possibly alleviates VIMS while viewers watch moving images.

Annex E
(informative)

Measurement method of visual global motion

E.1 General

It is necessary to measure several types of visual rotation speeds such as the yaw, pitch, and roll, which are defined in Annex C, from arbitrary images to meet the requirements or recommendations in 5.2.1, 5.2.2 or 5.3.2. The methods to estimate global motion can be categorized approximately as direct and indirect methods. In the direct methods, a global motion is obtained directly from the image signal pixel by the global minimization of cost functions. Meanwhile, the indirect methods contain two steps in general. A global motion is obtained at the second step based on the local motion resulted from the first step.

In this annex, one of the indirect methods that was proposed by Jinzenji et al.[24] is chosen as the specific method of visual motion estimation. This method is relatively simple and intuitive, characterized by its low computational cost, countermeasure against low-intensity gradients, and reduction in outlier effect. However, it has some limitations.

E.2 Basic framework of estimating visual rotation

Motion estimation is the process of determining motion vectors that describe the transformation from one 2D image to another, typically from adjacent frames in a video sequence. The motion vectors can relate to the whole image (global motion vector: GMV) or specific parts, such as rectangular blocks, arbitrarily shaped patches, or even per signal pixel (local motion vector: LMV). The motion vectors can be represented by a translational model or many other models that can approximate the motion of a real video camera, such as the roll, yaw, pitch, and zoom.

The method for estimating visual rotations consists of two stages. The first stage is to calculate the local motion vector or LMV, and the second stage is to estimate a global motion vector or GMV using LMV.

E.3 Estimating LMV

The motion vectors can be represented by a translational model or many other models that can approximate the motion of a real video camera, such as rotations and translations in all three dimensions and zoom. Many algorithms are available to estimate the LMV, and they can be classified into four categories: gradient techniques, pel-recursive techniques, block-matching techniques, and frequency-domain techniques. In these algorithms, the block-matching method is the simplest.

A block-matching algorithm involves dividing the current frame of a video into macroblocks and comparing each of the macroblocks with a corresponding block and its adjacent neighbours in a nearby frame of the video (sometimes only the previous one). A vector is created for each macroblock, such that the movement of the macroblock from one location to another can be represented. This movement, calculated for all the macroblocks comprising a frame, constitutes the global motion estimated in a frame.

The search area for better macroblock matching is determined by the search parameter, p, where p is the number of signal pixels on all four sides of the corresponding macroblock in the previous frame. The search parameter is a measure of motion. The larger the value of p, the larger is the potential motion and the possibility in obtaining a good match. However, a full search of all the potential blocks is a computationally expensive task. Typical inputs are a macroblock of size 16 signal pixels, and a search area of p = 7 signal pixels.

E.4 Estimating GMV

To calculate a global motion that well reflects the camera motion, this section clarifies the relationship between camera motion and local motion vectors (parallel motion model), and describes a method to select the global motion from local motion vector groups, which are proposed by Jinzenji et al.[25]. The camera motion can be described using the Hermart transform (four parameters affine) as per Formula (F.1):

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} a' & b \\ -b & a' \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} c \\ d \end{pmatrix}$$

$$a = a' + 1 \qquad \text{(F.1)}$$

where

u	is the horizontal component of motion vector calculated in each macro-block;
v	is the vertical component of motion vector calculated in each macro-block;
x	is the horizontal component of position of signal pixel;
y	is the vertical component of position of signal pixel;
a, a'	is the zoom component of global motion parameters;
b	is the roll component of global motion parameters;
c	is the translation component along yaw axis of global motion parameters;
d	is the translation component along pitch axis of global motion parameters.

First, the motion vector for each macroblock is calculated using the block-matching algorithm. The partial derivatives [see Formulae (F.2) and (F.3)] of the motion vectors are calculated for each macroblock. Based on the results, the GMV can be estimated.

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} = a' \qquad \text{(F.2)}$$

$$\frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x} = b \qquad \text{(F.3)}$$

Each partial derivative creates a significant cluster on a line written by Formulae (F.2) and (F.3) in each feature space. Here, all blocks with a smooth intensity gradation are removed from the target blocks in the global motion estimation process, because such motion vectors are not accurate and often concentrate around zero. The centroid of each cluster yields the zoom parameter and roll parameters. Hence, a' and b are detected.

Formula (F.1) can be transformed into Formula (F.4):

$$\begin{pmatrix} c \\ d \end{pmatrix} = \begin{pmatrix} u \\ v \end{pmatrix} - \begin{pmatrix} a' & b \\ -b & a' \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \qquad \text{(F.4)}$$

Subtracting the zoom parameter and roll effect from the block-based motion vector according to Formula (F.4) yields the transition parameters, i.e. yaw and pitch. The block-based transition parameters are clustered to identify the median values, which reflect the camera motion well.

E.5 Measurement process of visual global motion

The process for estimating the visual global motion is shown in the block diagram in Figure E.1.

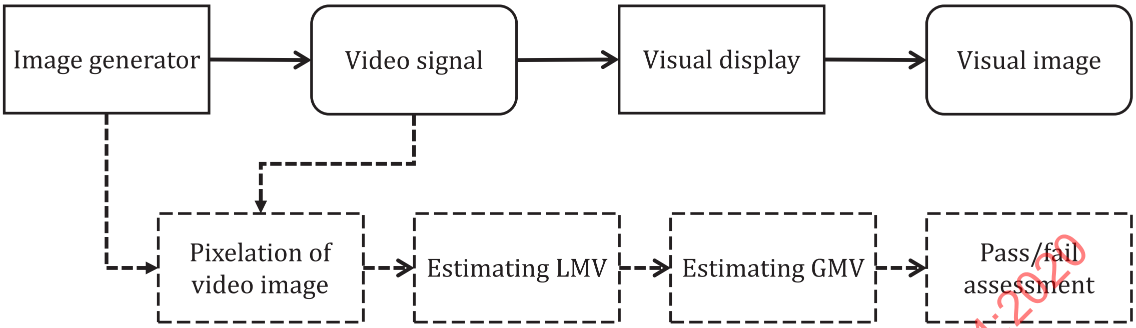


Figure E.1 — Signal stream of moving images and measurement process for conformance

E.6 Constraint

Several constraints in the estimation method of the GMV described in this annex are as follows.

— Shape and resolution of display: the shape is rectangular and the resolution of the display affects the suitable macro-block size.

— Ratio of background and foreground objects affects the accuracy of GMV estimation.

— Texture including repeatable or uniform pattern affects the accuracy of GMV estimation.