Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: http://www.tandfonline.com/loi/terg20

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**To cite this article:** Jelte E. Bos , Wietse D. Ledegang , Astrid J.A. Lubeck & John F. Stins (2013) Cinerama sickness and postural instability, Ergonomics, 56:9, 1430-1436, DOI: 10.1080/00140139.2013.817614

**To link to this article:** http://dx.doi.org/10.1080/00140139.2013.817614

*Ergonomics*, 2013
Vol. 56, No. 9, 1430–1436, http://dx.doi.org/10.1080/00140139.2013.817614

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# Cinerama sickness and postural instability

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(*Received 13 February 2013; final version received 26 April 2013*)

Motion sickness symptoms and increased postural instability induced by motion pictures have been reported in a laboratory, but not in a real cinema. We, therefore, carried out an observational study recording sickness severity and postural instability in 19 subjects before, immediately and 45 min after watching a 1 h 3D aviation documentary in a cinema. Sickness was significantly larger right after the movie than before, and in a lesser extent still so after 45 min. The average standard deviation of the lateral centre of pressure excursions was significantly larger only right afterwards. When low-pass filtered at 0.1 Hz, lateral and for-aft excursions were both significantly larger right after the movie, while for-aft excursions then remained larger even after 45 min. Speculating on previous findings, we predict more sickness and postural instability in 3D than in 2D movies, also suggesting a possible, but yet unknown risk for work-related activities and vehicle operation.

**Practitioner Summary**: Watching motion pictures may be sickening and posturally destabilising, but effects in a cinema are unknown. We, therefore, carried out an observational study showing that sickness then is mainly an issue during the exposure while postural instability is an issue afterwards.

**Keywords:** visually induced motion sickness; cybersickness; cinerama sickness; postural instability; balance

## 1. Introduction

It has been shown that watching motion pictures may cause increased postural instability and motion sickness, or more specifically visually induced motion sickness. The latter includes cybersickness, simulator sickness and cinerama sickness. This has been shown extensively in laboratory settings (e.g. Cobb 1999; Horlings et al. 2009), and when using flight simulators (e.g. Kennedy, Berbaum, and Lilienthal 1997; Kennedy and Stanney 1996). A positive correlation between postural instability and visually induced motion sickness has also been reported (Fukuda 1975; Owen, Leadbetter, and Yardley 1998; Stoffregen and Smart 1998; Takahashi et al. 1992; van Emmerik, de Vries, and Bos 2011). Yet, negative correlations have been reported as well (Reed-Jones et al. 2008; Stoffregen et al. 2008). Conversely, it has been shown that certain optic (flow) patterns may help to reduce physically induced motion sickness (Feenstra, Bos, and van Gent 2011), and to reduce vertigo in case of a malfunctioning vestibular system (Loader et al. 2007; Pavlou et al. 2004). Theories explaining these observations include ecological (Riccio and Stoffregen 1991) and control theoretical principles including specific visual–vestibular interactions (Bos 2011; Bos, Bles, and Groen 2008). The vast majority of the observations listed above concern 2D visual motion, where the same images are presented to both eyes. Presenting two slightly different images to the two eyes allows a 3D percept. With the increasing popularity of 3D movies, especially since Avatar in 2009, the number of press and internet comments on headaches, blurred vision and motion sickness symptoms has increased. According to Berezin (2010), up to 30% of 3D cinema attendants have ocular complaints. Yet, data on cinerama sickness and postural instability in a genuine cinema setting are still lacking. Moreover, if these effects persist after exposure, this might have safety consequences for work-related activities and vehicle operation.

We, therefore, aimed at testing the hypothesis that sickness and postural instability can be an issue during and/or after watching a 3D movie in a regular cinema setting. Given the assumed visual–vestibular interactions referred to (Bos 2011; Bos, Bles, and Groen 2008), with the vestibular system typically exhibiting relatively fast and the visual system showing relatively slow behaviour (de Wit et al. 1999), we also made a distinction between postural effects *per se* and those specifically in the low-frequency range. Although a comparison between the effect of 2D and 3D movies would be worthwhile, this was not an option within the present context of an observational study, and may better fit a laboratory setting. This paper, therefore, only presents data in response to watching a 3D movie in a real cinema, while yet elaborating theoretically on possible 2D/3D differences, both issues being of interest from a (social) ergonomics point of view.

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## 2. Methods

### *2.1. Cinema setting*

Postural stability was measured immediately before, right after and about 45 min after subjects watched a 3D aviation documentary for at least 1 h in a modern cinema. The subjects participating were all seated in the centre of the theatre on three consecutive rows. The screen was 9 m × 5 m ($w \times h$), and the average viewing distance was 7 m, resulting in an average field of view of about 65° × 39°. Circular polarised glasses were used to present two different image sequences to both eyes of the viewers.

### *2.2. Measurements*

In this study, we rated the subjects' sickness severity on a single valued 0–10 point misery scale (MISC): 0 indicating no problems at all and 10 vomiting (see also van Emmerik, de Vries, and Bos 2011). This scale exploits the fact that nausea (rated MISC 6 and up) is often preceded by other symptoms (rated 5 or less), such as dizziness, headache, (cold) sweat and stomach awareness.

Postural stability was measured during 60 s of quiet standing on a Nintendo Wii Balance Board™, approx. 32 cm × 51 cm × 5 cm, connected to a PC by means of Bluetooth, sampled at 40 Hz and low-pass filtered at 1 Hz. Following van Emmerik, de Vries, and Bos (2011), subjects had their feet in tandem stance (slightly apart to fit on the balance board), their hands resting on the contralateral shoulder, their heads slightly tilted backwards, eyes closed and their feet in a sharpened Romberg-like manner (Khasnis and Gokula 2003). To assess specifically low-frequency postural behaviour, time series were also low-pass filtered with a cut-off frequency of 0.1 Hz. Postural instability was quantified by means of the standard deviations ($\sigma$) of the centre of pressure in the for-aft ($x$) and lateral ($y$) directions for both frequency ranges. All individual post-measurements were then normalised by dividing their values by the matching pre-measurement values to control for individual differences in weight and stature. Van Emmerik, de Vries, and Bos (2011) used the same set-up and showed that without a specific intervention this ratio tended to decrease over a one-hour interval.

Two balance boards were available for simultaneous use, each subject carrying out her or his three tests with one board only. MISC ratings were taken just in advance of the balance tests. One combined MISC/postural stability measurement took less than 2 min.

### *2.3. Subjects and procedures*

This study was approved by the TNO Human Factors institutional Review Board on Experiments with Human Subjects. Nineteen subjects, 9 females and 10 males, in the age range of 21–66 years with an average of 42 years responded to an invitation to participate. They were given written information about the purpose of the experiment beforehand. After arrival at the cinema, they were given further explanation of the procedures, and they all gave their written informed consent. Baseline (momentary) MISC ratings and postural instability were measured in the foyer of the cinema, and are referred to as the pre-measurements. Subjects were then handed the polarised glasses, which could be worn over their own glasses, and they all watched a 60-min 3D aviation documentary with ample scene motion in all degrees of freedom. After the end of the documentary, the movie was restarted and subjects were taken out of the theatre one after the other with an average interval of 87 s to immediately carry out the post-exposure MISC and postural stability measurements. Actual average exposure to the movie was 74 min, in the range of 60–86 min. Right after the movie, subjects were asked to rate their maximum MISC score over the entire exposure. These measurements are referred to as the post1-measurements. And 36–64 min thereafter, with an average of 47 min, MISC and postural stability were measured once again, referred to as the post2-measurements.

Student's (paired) $t$-tests were used to calculate significances for differences, and Fisher's exact test to calculate the probability of finding specifically the observed number of subjects showing an instability ratio larger than 1 due to chance. Pearson linear correlation coefficients and significance levels were calculated relating individual MISC and postural stability ratios. A critical significance limit of 0.05 was adopted for all tests.

## 3. Results

Figure 1 shows the average MISC ratings before, during and after the movie exposure. Apart from the observation that at all times the average MISC was significantly larger than 0 ($p < 0.05$), the post1-values differed significantly from the baseline pre-values ($p = 0.003$). The post2 measurements were only marginally higher than the pre-values ($p = 0.07$). In addition to the number of subjects who did not feel perfectly well (i.e. MISC > 0), 5 out of 19 felt nauseated during the exposure, and one vomited twice.

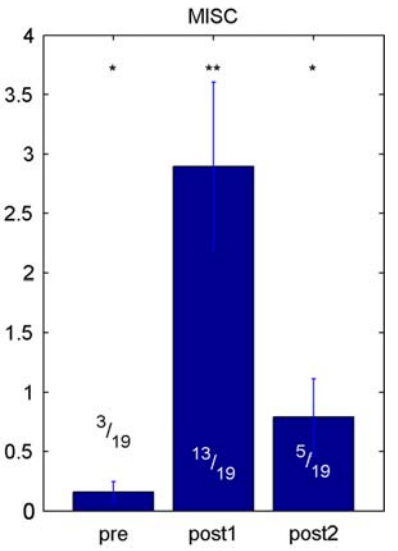


Figure 1. Average observed MISC-ratings before (pre), during (post1) and about 45 min after (post2) watching a 1-h 3D movie. Error bars show the SEM, ratios show the proportion of subjects not feeling perfectly well. * MISC $> 0$ with $p < 0.05$, ** id. with $p < 0.01$.

In addition to the subject who vomited and, therefore, had to interrupt watching the movie, two other subjects could not keep upright on the balance board for 1 min without making a corrective step. These three subjects have accordingly been excluded from the postural stability analyses.

Figure 2 shows the average standard deviations for the remaining 16 subjects for the normalised for-aft ($\sigma x$) and lateral ($\sigma y$) sway, only low-pass filtered with a cut-off frequency of 1 Hz. This figure also shows the proportion of subjects showing greater instability afterwards than before (i.e. normalised $\sigma > 1$). For these data, only the lateral sway right after the exposure was significantly larger than pre-exposure. Fisher's exact test showed that the chance of observing 12 out of 16 subjects having a postural instability ratio larger than 1 if caused by mere coincidence would only be 0.03 (11 or less giving $p > 0.05$).

Figure 3 similarly shows the postural data when low-pass filtered with a cut-off frequency of 0.1 Hz. In addition to the increase in lateral sway right after the exposure, low-frequency for-aft sway also was increased, and this effect was still

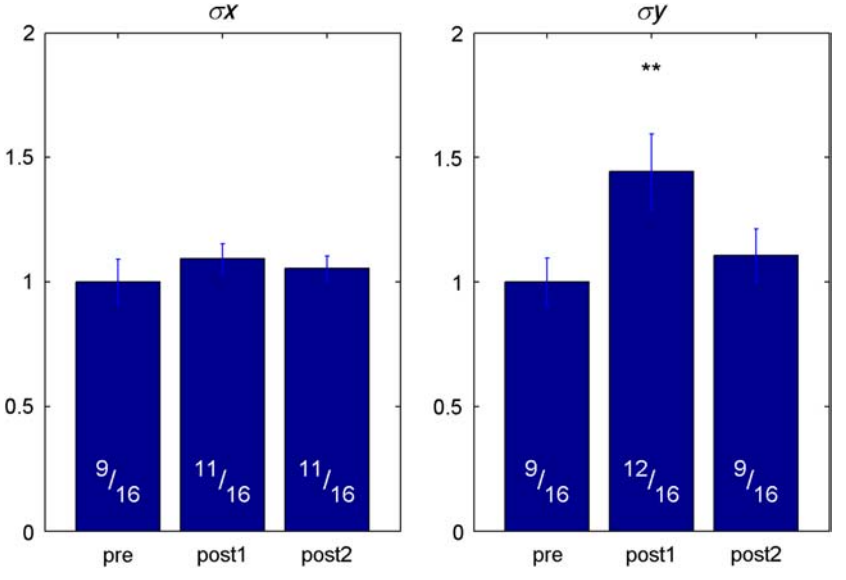


Figure 2. Average standard deviation of for-aft ($\sigma x$) and lateral ($\sigma y$) sway, low-pass filtered at 1 Hz and normalised with respect to the baseline (pre) measurements. Error bars show the SEM, ratios show the proportion of subjects with a normalised standard deviation larger than 1. ** A normalised $\sigma > 1$ with $p < 0.01$.

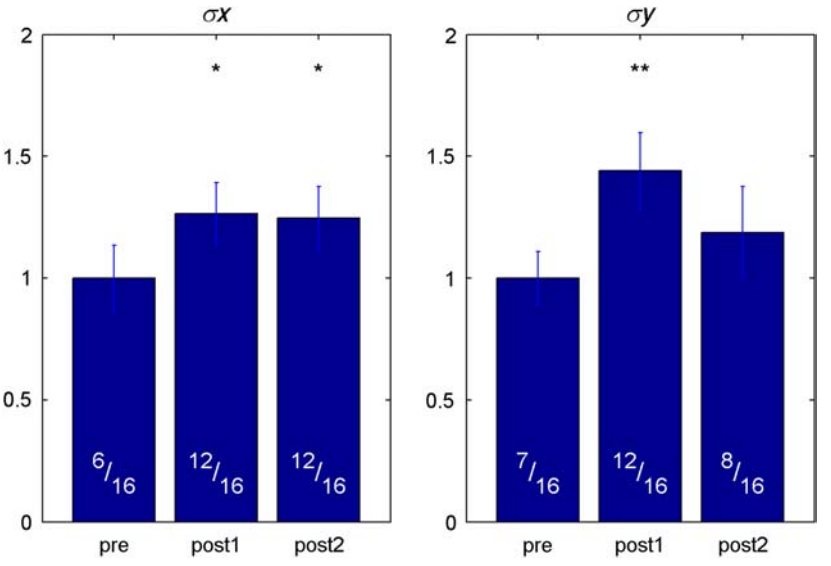


Figure 3. Average standard deviation of for-aft ($\sigma x$) and lateral ($\sigma y$) sway, low-pass filtered at 0.1 Hz and normalised with respect to the baseline (pre) measurements. Error bars show the SEM, ratios show the number of subjects with a normalised standard deviation larger than 1. * A normalised $\sigma > 1$ with $p < 0.05$, ** id. with $p < 0.01$.

present after about 45 min. Fisher's exact test applied to the proportion of subjects showing an instability ratio larger than 1 confirms these conclusions here as well.

No significant correlations were observed between the MISC ratings and any of the postural instability ratios.

## 4. Discussion and conclusions

In addition to sickness and postural instability induced by watching motion pictures already known from laboratory studies, in this study we showed that in an unselected sample of cinema goers, significant sickness during and increased postural instability after watching a movie are also an issue in a cinema. Moreover, we showed that the low-frequency ($<0.1$ Hz) for-aft postural instability component remained significantly elevated for at least 45 min. These conclusions can be drawn both based on sample averages and based on the proportions of subjects showing a larger instability afterwards than prior the exposure. Yet, because the data presented concern an observational study, these conclusions should be substantiated by including a control group.

Although 1 subject (out of 19) did vomit in this experiment, this probably overestimates the sickness incidence observed over a larger population. Inquiries with the cinema staff revealed that about 1 out of every 1000 visitors do actually report a vomiting incidence due to watching a 3D movie, where as many seem to pay a visit to the toilet for the same reason without explicit notice. More people probably suffer from sickness without vomiting, and generally do see the film out, sometimes interrupted by a short pause. These pauses are also used for taking medication against headaches and sickness, as known from requests to the cinema staff. A difference regarding sickness incidences between different 3D movies, both regarding content and duration, is known. Here, we utilised a movie with pronounced 3D effects as well as ample Earth motion (relative to an aircraft fixed camera view), the latter known to affect motion sickness in particular (Bos, Bles, and Groen 2008; Golding et al. 2009, 2012). We, therefore, estimate the actual vomiting incidence to be 1/500 for watching 3D movies in a cinema. Similar observations on 2D movies reveal an estimate of about 1/5000 vomiting occurrences, with the explicit comment that alcohol also seems to be an issue in these cases. Although solid statistics about the overall problem are still lacking, the tenfold difference in estimated sickness incidences between 2D and 3D movies cannot be ascribed to alcohol *per se* (although alcohol may have an aggravating effect), the visual effect most likely being the main reason.

The increase in postural instability immediately after the movie exposure was largest for lateral sway. This effect may be attributed to the quasi-tandem stance used in this experiment, making the test more sensitive for lateral than for for-aft motion. However, when focusing on slow movements only, i.e. movements with frequencies below 0.1 Hz, for-aft motion was affected too. Interestingly this for-aft low-frequency instability remained elevated for at least 45 min after the exposure,

whereas lateral sway returned to baseline within that period, irrespective of the frequency tested. Here, we assume that this directional difference relates to an improper depth perception that may typically be associated with artificial 3D images. Binocular viewing, furthermore, has been shown to affect postural stability differently than monocular viewing does (Le and Kapoula 2006), and erroneous depth perception has been shown to cause spatial disorientation and falls on escalators (Cohn and Lasley 1990). As a consequence, it therefore makes sense to assume that watching 3D artificial images causes more sickness and instability than watching 2D images does. Due to the limited design in this study, this hypothesis, however, remains to be validated.

There is yet another reason why watching artificial 3D images may be more provocative with respect to both visually induced motion sickness and postural instability than watching 2D images. When focusing on the effect of internal and external fields of view, it has been assumed that the *least* sickness occurs when these fields are equal (Draper et al. 2001; Kolasinski 1995). Here, the internal field of view (iFOV) refers to the viewing angle of the camera used to create an image, and the external field of view (eFOV) to the observer's viewing angle when looking at the projection of that image on a screen. However, van Emmerik, de Vries, and Bos (2011), using a variety of iFOV and eFOV settings, reported the *most* sickness when the two fields of view were equal. As a consequence, they concluded that 'quarantining' as suggested by Golding et al. (2009) is probably an issue, i.e. our central nervous system may be capable of dealing with subtle discrepancies between the iFOV and eFOV, but larger differences are judged unnatural, cannot be dealt with, and therefore lead to less sickness. Also because visually induced motion sickness is absent in labyrinthine-defective patients (Cheung, Howard, and Money 1991), we assume that this sickness is primarily caused by a visual–vestibular conflict, and this conflict is modulated by visual–visual conflicts such as the conflict between the iFOV and eFOV. In line with the quarantining hypothesis (Golding et al. 2009), the effect of this modulation is larger the more natural the visual scene is presented. Because 3D images may give a more natural visual experience than 2D images, 3D images may hence also give rise to more sickness than 2D images, as seems to be the case indeed according to the aforementioned observation of cinema staff.

In contrast to other reports (Fukuda 1975; Owen, Leadbetter, and Yardley 1998; Stoffregen and Smart 1998; Takahashi et al. 1992; van Emmerik, de Vries, and Bos 2011; Reed-Jones et al. 2008; Stoffregen et al. 2008), we did not observe significant correlations between MISC ratings and postural instability ratios in this sample of subjects, neither positive nor negative. One reason may be the relatively large range of ages of the subjects participating in this study, age having an effect on motion sickness (Bos et al. 2007), and older people likely having more non-vestibular postural deficiencies than younger people, thus increasing the variability of data in this study.

Although press and internet notifications do mention negative side effects of watching motion pictures and game playing, solid statistics on these effects are not available. Moreover, these effects mainly focus on accommodation–vergence conflicts with respect to 3D images (Howarth 2011; Pölönen Järvenpää, and Bilcu 2013). Although lens accommodation and (con)vergent eye movements are linked by the central nervous system, watching stereoscopic 3D images requires accommodation to be fixed to the plane of projection and the eyes being able to converge independently from accommodation. It is, therefore, suggested that uncoupling this synergy, especially in young children, hampers a healthy development of vision (see e.g. Italian Ministry of Health 2010). In contrast with these well-known accommodation–vergence conflicts, visual–vestibular conflicts are largely underexposed. Moreover, to our knowledge, such data induced by watching a 3D movie in a cinema had not been published before, this study (partly) filling this gap. Likewise, comparable data from playing computer games and watching home videos are still lacking. Assuming that more time is spent on these activities than on an occasional visit to a cinema, the effects thereof may even be larger. Given our findings presented here, we conclude that visually induced motion sickness and postural instability are cause for concern in consuming stereoscopic 3D images with motion in everyday life.

From an applied point of view, we lastly conclude that this concern may also involve a risk for work-related activities and vehicle or machinery operation. It tells, for example, that in certain countries postural instability is taken as a criterion for safe driving after suspected alcohol intake, and several studies have shown that alcohol may indeed induce postural instability (Modig et al. 2012; Nieschalk et al. 1999). Although comparing the effect of visual motion with that of alcohol is somewhat like comparing apples with oranges, the comparison is yet not completely irrational. Vestibular function is already known to be affected by both (Bos 2011; Bos, Bles, and Groen 2008; Chiang and Young 2007; Modig et al. 2012; Nieschalk et al. 1999; Post et al. 1994; Ross and Mughni 1995). Another indication for possible risks comes from aviation, where it is not uncommon to ground pilots for 12 h after a simulator training, where visual motion is at issue too, and postural instability has been shown as well (Kennedy, Berbaum, and Lilienthal 1997). Yet, to our knowledge, data on the actual risks lacks here too, which also justifies further research on both alcohol and on 2D and 3D visual motion-induced postural instability.

In summary, we conclude that sickness and increased postural instability after watching stereoscopic 3D image motion is an issue in everyday life situations, as shown here in cinema goers, sickness typically returning to baseline shortly after

the exposure, and low-frequency for-aft postural instability remaining enlarged for at least 45 min. These issues may give a possible, but yet unknown risk for work-related activities and vehicle operation, and 3D visual motion may cause more serious problems than 2D images do. The latter assumption, however, awaits validation.

**Acknowledgements**

This work was facilitated by the Dutch Ministry of Defence within the framework of the project V937 Improved Performance at Motion, by VARA's consumer TV programme Kassa!, and by CineMec Ede, Netherlands. None of these organisations had any involvement in the study design, in the collection, analysis and interpretation of the data, in the writing of the manuscript and in the decision to submit the manuscript for publication. Lidwi van Geest is acknowledged for her help in performing the experiments.

**Notes**

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