The metrics for measuring motion sickness

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Abstract *– Motion sickness can be measured via a variety of self-report rating scales. These scales either focus on the progression of symptoms or on mere feelings of illness. It is unclear how these constructs relate to each other, which not only prevents a valid choice for a specific rating scale in studies on motion sickness but also complicates the interpretation and comparison of results between studies. For those reasons, we investigated this relationship by asking 114 subjects to rate the level of illness they associate with the symptoms used to describe the progression of motion sickness in the MIsery SCale (MISC). We did so by magnitude estimations and a two-alternative forced choice task. As a prerequisite, we confirmed that the MISC captures the progression of symptoms. We subsequently established that feelings of illness increase with the progression of symptoms, except for a considerable reduction of illness midway, at the transition of pre-nausea symptoms to nausea. This implies that a decrease in illness is not equivalent to a reversal in progression of symptoms. We conclude that the MISC does measure the progression of symptoms, while measures of illness are not suitable to monitor motion sickness progression.*

Keywords: *motion sickness, scaling, illness, symptoms*

Introduction

Motion sickness is a syndrome that may occur after exposure to real or virtual movement and has been a well-recognized issue since ancient times. Motion sickness is currently gaining interest in particular with respect to self-driving cars and to virtual reality (VR) [e.g. Die16, Isk19, Jon18, Kim18, Kui19, Reb16]. The majority of all car occupants are currently drivers, who rarely get carsick [Ken14, Rol91]. The increasing interest is however well-deserved when considering that two-thirds of car passengers do suffer from motion sickness [Rea75, Sch20], implying the issue is relevant to autonomous driving. Although the incidence of virtual reality sickness is still not well known, it is generally considered to be the major drawback limiting its use [Reb16, Yil19].

Symptoms associated with motion sickness in general include an overall feeling of malaise, accompanied by (cold) sweating, increased salivation, drowsiness, pallor, nausea, and vomiting [Dob19, Lac14, Law14a, Law14b]. Pre-nausea symptoms such as dizziness, headache, (cold) sweating, tiredness, salivation or burping usually comprise the first manifestations of motion sickness, although large variability is recognized between individuals [Bos05, Law14b, Rea75]. After prolonged exposure, symptoms can progress towards nausea, retching, and eventually culminate in vomiting.

Numerous self-report scales have been developed over time to measure motion sickness. The Simulator Sickness Questionnaire [Ken93] and Motion Sickness Assessment Questionnaire [Gia01) concern multiple symptom checklists. These lists provide the advantage of a multidimensional assessment, but application is time consuming and may interfere with a task, if at issue. Single answer numerical rating scales offer an advantage as they can be applied quickly and repeatedly during experiments. Examples include the Fast Motion Sickness scale [Kes11], the MIsery SCale (MISC) [Bos05], and Griffin's and Newman's rating scale [Gri04]. Some of these scales emphasize the progression of symptoms, implicitly asking how close someone is to vomiting. Other scales focus on mere feelings of illness, by which we mean the unpleasantness of the experienced symptoms. Both sorts of scales have proven their usefulness in motion sickness research. However, it is currently unclear how feelings of illness relate to the progression of symptoms; do we consistently feel worse as symptoms progress? This lack of knowledge not only prevents a valid choice for a specific rating scale in studies on motion sickness, but also complicates the interpretation and comparison of results between studies.

In this study, we aim to find out how feelings of illness relate to the progression of symptoms. To that end, we elaborate on the MISC in the first part of this study to assess whether it captures the progression of symptoms. In the second part, we then asked subjects to rate the level of illness they associate with the various sets of symptoms used to describe the progression of symptoms as rated by the MISC.

Methods

Progression of Symptoms

The MISC is an ordinal 11-point single answer rating scale based on the progression of symptoms: no symptoms (0-1), pre-nausea symptoms (2-5), nausea (6-9), and vomiting (10); using a severity grading within these categories as listed in Table 1 [Bos05]. Along with the advantage of its quick assessment, each numeric value of this scale is linked to a symptom description, which can be assumed to minimize interindividual differences.

Table 1: The MIsery SCale (MISC) (Bos et al., 2005).

Symptoms		MISC
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, yawning, headache, tiredness, sweating, stomach / throat awareness, burping, blurred vision, salivation, … but no nausea	vague	2
	little	3
	rather	4
	severe	5
Nausea	little	6
	rather	7
	severe	8
	retching	9
Vomiting		10

We (re-)analysed MISC ratings from four experiments - referred to as E1 [Bos05], E2 [Bos15], and E3-E4 (data unpublished yet). Subjects were passively exposed to physical motion sickening stimuli in all of these studies. E1, E3 and E4 applied multiple trials with horizontal and vertical oscillations of varying frequency and amplitude for a maximum duration of thirty minutes. E2 applied off-vertical axis rotation at a fixed frequency and angle of tilt. Subjects were restricted from outside vision or blindfolded in all but one experimental condition in E1. Cognitive distraction tasks (n-back tasks, memory tasks) were used in the majority all experiments except for one condition in E2.

MISC ratings were obtained repeatedly with intervals of 2 or 5 minutes until either the planned end of the trial, when a stop criterion of MISC ≥ 7 was reached, or when a subject wanted to stop by him- or herself. The 152 healthy adults participating in E1-E4 performed 528 trials with at least two MISC ratings within each trial (Table 2). All experimental protocols obtained ethical approval by TNO's Institutional Review Board. Subjects had experienced symptoms of motion sickness in the past five years and were free of vestibular disorders. Experiments E3 and E4 were supplemented with two additional measurements on the feelings of illness associated with the progression of symptoms as rated by means of the MISC, see the next part.

Table 2: Experimental details.

Experiment	*n*	trials	Duration	interval
E1	24	72	30'	5'
E2	17	65	20'	2'
E3	29	81	20'	2'
E4	82	310	20'	2'

Symptomatology versus Illness

We used two methods to assess the level of illness associated with the various symptom descriptions as applied in the MISC in E3 and E4. The first method is **magnitude estimation** (MAG), a method originally used for the ratio scaling of psychophysical stimuli [Ste56] and social phenomena [Lod81]. We here asked subjects (*n*=109) to draw lines which lengths represented the level of illness they associated with each MISC (1 to 10) symptom description. A 10.5 cm reference line was provided, representing the level of illness as described for MISC 6 (a little nauseated) in E3 and for MISC 4 in E4 (see Table 1). Subjects were explained that drawing a line twice as long as the reference line represented that the listed symptom would cause twice the amount of discomfort than the reference symptom. Corresponding MISC values were carefully omitted. We measured the line length (L) for each question with a ruler. Normalized magnitude estimations were calculated within each subject by using MAG = (L-Lmin)/(Lmax-Lmin), which will further be referred to as MAG6 and MAG4, depending on the reference used (MISC 6 and MISC 4 respectively). This normalization results in $0 \leq$ MAG ≤ 1, maximizes the effect of differences within subjects, minimizes the effect of differences between subjects, and allows for an optimally balanced comparison of the effects considered below.

The second method we used was a **two-alternative forced choice** (2AFC) task. In E4, we let subjects (*n*=83) perform pairwise comparisons [Thu27] between the symptom descriptions of the MISC categories as also used in the magnitude estimation task (again without referring to the associated MISC values), by asking "which of these two symptoms do you think of as most unpleasant?". Ignoring the order of the two symptom descriptions within each comparison, this resulted in 45 comparisons that were presented randomly. For each MISC category we then counted the number of occurrences in which a subject rated that symptom as the most unpleasant. Within each subject we again normalized these counts (C) by defining the variable 2AFC = (C-Cmin)/(Cmax-Cmin), with $0 \leq$ 2AFC ≤ 1.

Results

Progression of Symptoms

To ascertain that the MISC captures the progression of symptoms, we analysed the distribution of observed transitions between consecutive MISC ratings within the data from experiments E1-E4. We found in 88.8% of the cases either no change or an increment of 1 MISC value. Decrements were only present in 4.2% of all cases; these occurred most often at ratings 5 and 6. Changes of more than one MISC category were observed in 7.4% of the cases, generally to and from MISC 4-6.

Symptomatology versus Illness

In experiments E3 and E4 we added two tasks to investigate the relationship between the feelings of illness associated with the progression of symptoms. We here present the connected median illness ratings for the MAG6 (in yellow), MAG4 (in blue), and 2AFC (in red) tasks plotted versus the progression of symptoms as rated by means of the MISC in Figure 1. From this figure, three similar positive relationships stand out, as does the exceptional rating behaviour at MISC 5 and 6.

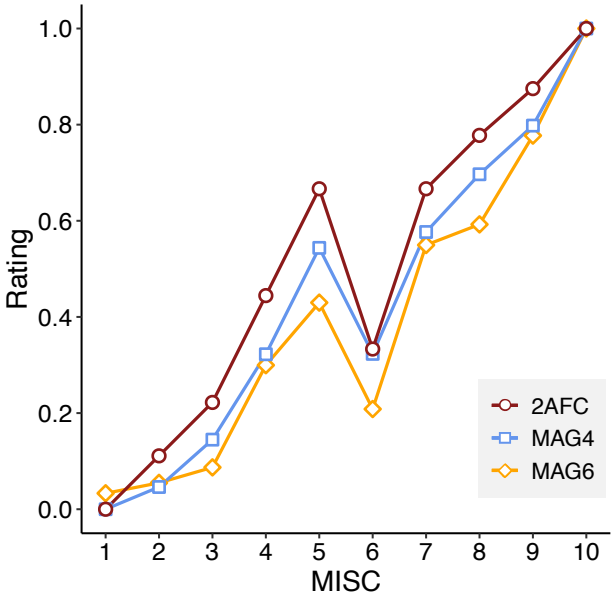

Figure 1: Illness ratings versus the progression of symptoms for three ways to assess the illness rating.

Discussion

In this study we investigated how feelings of illness relate to the progression of symptoms. We first confirmed that the MISC captures the progression of symptoms. Subsequently, we asked subjects to rate their feelings of illness associated with the symptom descriptions applied by the MISC. We find that overall feelings of illness increase with the progression of symptoms, but that there is an exception halfway through the development at the transition from pre-nausea symptoms to nausea. Apparently, people generally consider feeling a little nauseated (MISC 6) to be less unpleasant than severely suffering from any of the pre-nausea symptoms (MISC 5).

This anomaly occurs at the MISC categories that showed the largest rating variability in MISC transitions. Despite having a larger variability, ≥80% of the transitions for these categories were still those of no change or an increment of 1 MISC value. This implies that MISC 5 and 6 should not be reversed and the current order of the MISC does capture the progression of symptoms. The larger rating variability for the MISC 5 and 6 categories thus cannot be the explanation of the observed decrease in illness. It hence makes most sense to conclude that feelings of illness do not always increase coherently with the progression of symptoms.

Looking at the separate illness measurement methods, Figure 1 shows that the ratings obtained via either MAG or 2AFC behave very similarly. Nevertheless, forcing people to choose between two symptoms has explicated the contrasts in this relationship and therefore results in more pronounced effects for the 2AFC task. This measure thus seems more sensitive as compared to MAG.

Two studies have previously addressed related questions. Reason and Graybiel [Rea70] reported that illness ratings generally increase over time during a motion sickening stimulus. They however also reported the existence of some (short-lived) decreases in those ratings during prolonged exposure, in line with our observation that feelings of illness do not increase monotonically with the progression of symptoms. Bos et al. [Bos05] reported a high positive correlation between the progression of symptoms and their rated severity, following the overall pattern that is visible in Figure 1. Both of these studies are in line with the overall relationship between illness and progression we found, but did not report the specific decrease of feelings of illness at MISC 6. Our study could not confirm the feelings of (partial) relief associated with vomiting [Dob19, Lac14, Leu19], which would predict a decreased rating at MISC 10 as well, which may simply be explained by our subjects not having been made that sick.

Given the decrease of illness midway the progression of symptoms, caution is advised when comparing studies that have used different scales and in choosing a measurement method for experimentation. We conclude that there is a fundamental difference between feelings of illness (related to unpleasantness) and the progression of symptoms (indicative as a precursor of vomiting). The latter may be of particular relevance with respect

to carsickness, because stopping or leaving a car while in traffic to prevent vomiting is less feasible than putting off VR goggles, for example. In carsickness research the MISC therefore offers specific advantages, while in VR as most often used for fun (gaming), measures of illness seem more relevant. We furthermore observe that a decrease in illness is not equivalent to a reversal in progression of symptoms (i.e. reports of improvements in illness do not imply the turnaround of a progressive syndrome). We conclude that measures of illness are not suitable to assess the progression of symptoms while on the other hand, the MISC does measure the progression of symptoms and may be used to predict illness. This could be achieved via a lookup table that would allow for parametric statistical testing of hypotheses as impeded by the ordinal nature of the MISC itself, a topic we are still elaborating on.

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