Motion Predictability and Sickness

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Abstract

Although the effect of motion predictability on motion sickness seems common knowledge, relevant literature is scarce. We therefore performed two experiments. In Experiment A, 17 subjects were exposed to 15 minutes of repeated forward/backward motions on a linear sled, repeated within subjects in three ways: 1) using identical motions interrupted by equal standstills, 2) using randomly reversed motions interrupted by equal standstills, and 3) using identical motions interrupted by semi-randomly varied intervals of standstill. In Experiment B, 20 subjects were exposed to similar motion in which both temporal and directional factors varied. Within subjects, this profile was presented in two ways: 1) each motion being preceded one second ahead by a sound-clip telling “forward” or “backward”, and 2) the same cues presented during the motion. Sickness was rated using an 11-point misery-scale. Experiment A revealed no difference between the two unpredictable conditions, which gave 52% higher sickness ratings than the predictable condition. Experiment B revealed that audio cues preceding such unpredictable motion may then reduce sickness ratings by 17%. We conclude that 1) unpredictability of motion increases motion sickness, which effect, 2) can be decreased by adding a cognitive cue preceding an otherwise unpredictable change of motion.

Keywords motion, motion sickness, predictability, anticipation

Introduction

Motion sickness may affect passengers of cars typically more than it affects drivers. The difference has been ascribed to anticipation, e.g., [Che12, Rol91], assuming drivers make use of an optimal set of information including their knowledge on the vehicle’s behaviour as a result of them controlling the vehicle. Drivers, for example, do know when they (will) initiate certain actions such as steering and pushing the gas or brake pedal. This information is typically absent in passengers. Yet, passengers may benefit from knowing in advance the direction of curves when looking ahead, which is known to be beneficial with respect to motion sickness, different from looking rearward [Kui18]. The beneficial role of anticipatory motion has also been shown when using an artificial display showing the trajectory to be followed [Fee11]. Apart from such anticipatory information, it makes sense to assume that periodic motion being inherently predictable, may also be less provocative with respect to motion sickness as compared to unpredictable motion events like discrete accelerations and decelerations. These issues seem of particular interest with respect to self-driving cars [Die16, Bos16]. Apart from the references referred to above, the literature on the effect of predictability is scarce. We therefore performed two experiments studying these effects separately. In Experiment A we studied the effect of predictability of a motion per se, and Experiment B we studied the effect of audio cues preceding specific motion events. This paper summarises and elaborates on [Kui19] and [Kui20], in which these experiments have been described separately.

Methods

Apparatus

In both experiments we used a 45 m linear sled, with a fully enclosed cabin housing a rally seat with a headrest and a five point safety belt as shown in Figure 1. The cabin prevented any outside view and somatosensory cues caused by wind. Its interior was illuminated and subjects were instructed to keep their eyes open. A two-way audio connection was maintained throughout the experiment by means of a headset. Pink noise was added to mask any sounds related to the cabin motion.

Motion profiles

In both experiments single fore-aft 9m displacements were used, lasting 8 s each, either applied forward-backward or reversed, backward-forward,

returning the cabin to its starting position. These displacements were repeated during 15 minutes with, on average, 8 s intervals of stand still. In all conditions detailed below, each displacement had an individual peak acceleration of 2.5 m/s^2, resulting in an average overall acceleration (including the periods of standstill) of 1.25 m/s^2 and a peak in the power spectrum at 0.13 Hz. These values are within the range of those observed in actual car driving. The sickening effect calculated according [ISO97] was equal for all conditions as well, ignoring this reference only holds for vertical motions.

Figure 1. Linear sled with cabin (left) oriented to move a subject fore-aft, sitting in a rally seat (right).

Experiment A

In this experiment the predictability of motion per se was varied directionally and temporally. In a control condition (P) the repeated motion was always equal, i.e., forward-backward using fixed intervals of 8 s, thus resulting in a perfectly predictable periodic motion. In another condition (dU), the direction of the motion was reversed randomly while keeping the interval fixed at 8 s. In a third condition, the direction was fixed, but the interval was varied randomly between 2 and 14 s with an average of 8 s.

Experiment B

In this experiment, only one motion profile was used, combining the temporal and directional variabilities applied in Experiment A. Audio cues were either presented at random moments during the motion (C), or 1 s in advance of the actual motion (A). The audio cue was included in the control condition (C) to eliminate a possible effect of the audio cue per se in case this would have been omitted. Figure 3 shows these two stimulus combinations.

Sickness ratings

In both experiments, sickness was rated every minute by means of the MIsery SCale (MISC [Bos05a]). The MISC is an 11-point scale based on the progression of symptomatology (0: no problems, 1-5: vague to severe symptoms except nausea, 6-9: slight to severe nausea, 10: vomiting), allowing swift subject responses with minimal interference. See [Reu20], this conferences for a comparison between the symptoms based MISC and subjective illness.

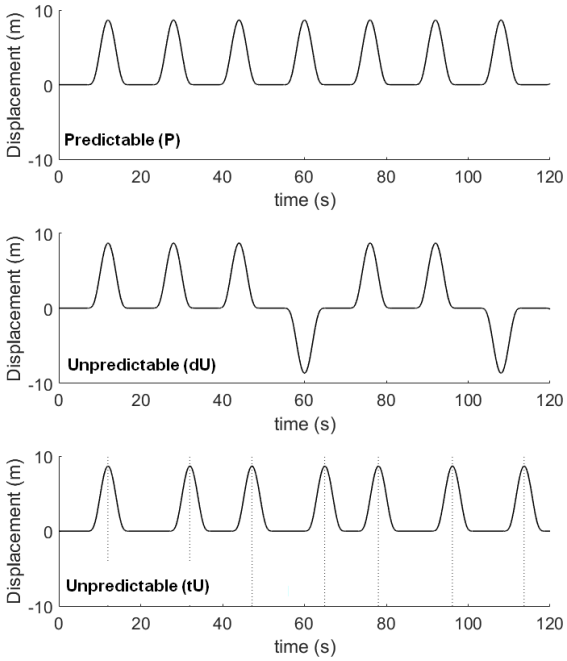

Figure 2. Motion profiles used in Experiment A.

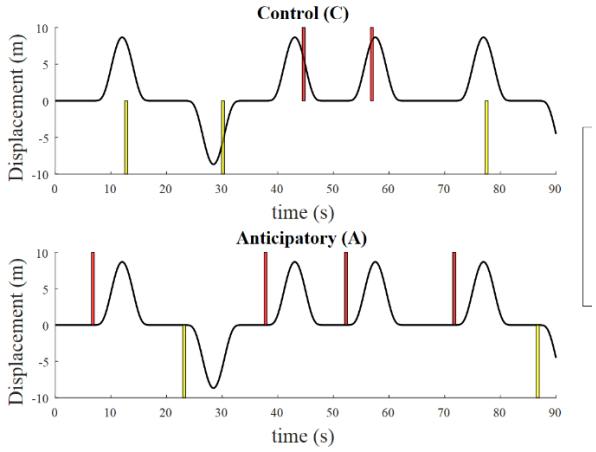

Figure 3. Motion profiles used in Experiment B. Here, the red upper vertical bars indicate the moments the "forward" audio cue was given and the yellow lower bars the "backward" cue.

Subjects and procedures

Both experiments were approved by the TNO Institutional Review Board and the experiments were realised within the applicable laws and regulations on non-medical research with human subjects.

Experiment A

In Experiment A, 17 subjects (12 females, 5 males, 40 ±11 (sd) year of age) participated in all three conditions on separate days. The order of conditions was balanced over subjects (except for one case).

Experiment B

In Experiment B, 20 subjects, (8 females, 12 males, 39 ±13 (sd) year of age) participated in both conditions on one day with an hour in between the conditions. The order of conditions was balanced over subjects.

Results

Figure 4 shows the MISC time courses obtained in Experiment A (top) and B (bottom).

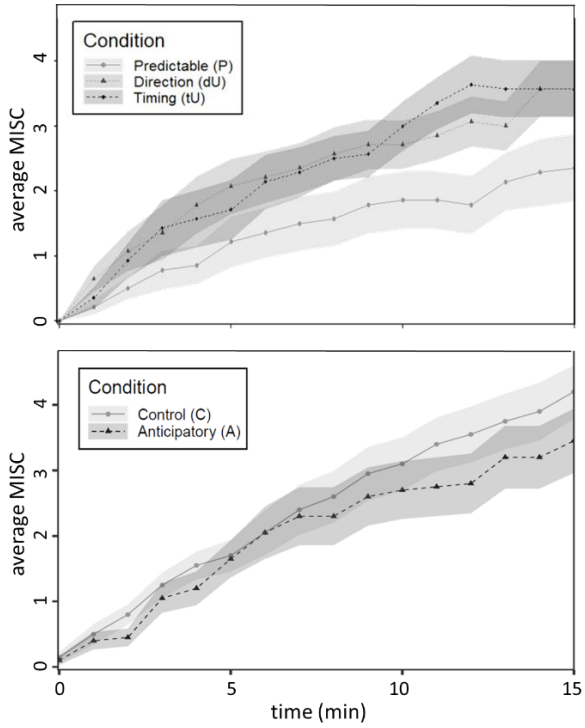

Figure 4. Average MISC ratings observed in experiments A (top) and B (bottom). Gray areas represent SEM.

Table 1 lists the average illness ratings after 15 minutes in both experiments. Repeated measures ANOVAs showed a significant effect of time in both experiments (A: $p < 0.001$, B: $p < 0.001$) and condition (A: $p < 0.001$, B: $p < 0.025$). Post hoc tests showed that both unpredictable conditions in Experiment A differed from the predictable condition (dU/P: $p = 0.008$; tU/P: $p = 0.012$), while the unpredictable conditions did not differ mutually.

Table 1. Average MISC values after 15 minutes of exposure observed in Experiments A and B

Exp		**A**			**B**
Cond	P	dU	tU	C	A
mean	2.36	3.58	3.6	4.15	3.45
sd	1.95	1.65	1.7	1.82	2.19

Discussion and conclusions

In both experiments described, we studied the effect of predictability of motion on motion sickness. In Experiment A this concerned the predictability of the motion per se, and in Experiment B this concerned an audio cue preceding a specific event. In both experiments, we showed that predictability reduced sickness significantly. From Table 1 it can be concluded that on, average, unpredictable motion may result in a 52% higher sickness rating than predictable motion, and informative audio cues preceding such unpredictable motion may then reduce sickness ratings by 17%.

The smaller effect found in Experiment B may partly be explained by the fact that the audio cue only concerned the initial part of the displacement away from the starting point, where the second returning part was in the reverse direction to the one mentioned by the audio cue. In real on-road conditions, accelerations and decelerations are generally lacking this bi-directional behaviour and may therefore be signaled more clearly (though then with respect to acceleration and deceleration instead of displacement), thus supposedly resulting in a larger effect.

The lesser reduction in Experiment B may also partly be understood by the fact that we presented the audio cues only 1 s in advance of the actual motion onset. Different types of cues, e.g., vibrotactile, and/or different interval times may result in larger effects as well.

Furthermore we used a unidirectional stimulus, while real car motions are unpredictable along three axes. In that respect it can be anticipated that an appropriate 3D directional cue applied at the right time will further increase the effect.

The effects of predictability reported on here, lastly, is much smaller than the effect found by [Fee11], who used a visual stimulus. In that respect, however, we assume the effect of visual information to be fundamentally different from auditory (or even haptic) cues. Visual signals are known to project on the vestibular nuclei as do vestibular signals, implying that, visual and vestibular cues both directly give rise to, self-motion and orientation perception, while the other signals do require (cognitive) processing (see further below). Alternatively, using an abstract visual cue, though likely giving a similar effect, would be less practical given the fact that it requires specific visual attention.

Apart from the differences between the conditions within both experiments reported on here, the experimental circumstances were otherwise equal. This allows for a comparison of the combined effect of temporal and directional unpredictability as studied in Experiment B and separately in Experiment A. From Table 1 it can be concluded that the combined effect resulted in an increase of

sickness by 76%, while this was 34% for the separate conditions. This suggests that temporal and directional effects just add about linearly, at least in this particular case.

From a theoretical point of view, these results can be understood when considering an internal model, or neural store, making a prediction or expectation about self-motion. The conflict between this expectation and (integrated) sensory information about self-motion has been assumed to result in sickness [Ble98, Bos98, Oma82, Rea75]. The results of Experiment A can then be understood by a continuous updating of the neural store, taking advantage of the repeated exposure to the same motion again and again, which, apparently, already makes a difference within two minutes. To explain the result of Experiment B, it is essential to consider the fact that the audio cue requires cognitive processing before its meaning can be integrated in the neural store about self-motion. This internalisation process likely requires additional time. The curves C and P from Figure 4 seem to support this assumption. During the first 7 minutes these curves grow approximately equal, only after which time they grow away from each other. Interestingly, though not noticed at that time, a comparable effect can be seen in data published by [Gri04]. Larger exposure times can then be assumed to allow for a better internalisation and hence a larger effect.

From an applied point of view, the current data seem of particular interest with respect to self-driving cars. Occupants will then be engaged in non-driving activities more than is currently the case, thus being more prone to carsickness [Die16, Bos16]. Although medication can be effective, their sedative effect is a major drawback in case a transfer of control would still be required, or when safety critical task have to be performed right after the road trip. Then, alternatives should be considered, and the data presented in this paper offer a way to go. Considering that audio cues may interfere with other activities, in particular those requiring audio communication, haptic cues may offer a promising alternative. these may be of particular interest, not least because these have been shown to be effective in countering spatial disorientation, a phenomenon closely related to motion sickness [Bos05b]. Moreover, given the significance of the effects currently reported on, the fact that this was only a first attempt to look at possible differences, and the shortcomings discussed that may be overcome, it makes sense to assume there is ample room for improvements.

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