OBJECTIVE AND SUBJECTIVE TIME COURSES OF RECOVERY FROM MOTION SICKNESS ASSESSED BY REPEATED MOTION CHALLENGES

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Abstract — The aim of this study was to determine whether the time course of recovery of tolerance, as assessed objectively by rechallenge with motion, paralleled the subjective recovery from motion sickness. Subjects (n = 20) were exposed to 5 pairs of nauseogenic motion challenges in which the time interval between the end of the first and the start of the second of each pair ranged from 15 min to 2 h. The cross-coupled motion challenge had an incrementing profile of rotational velocity from 4° to 92°.s⁻¹ in steps of 4°.s⁻¹ every 30 s, with 8 head movements per 30 s, of approximately 45°, and was continued to the point of moderate nausea. Objective loss of tolerance decreased from 15 min to 60 min after the first challenge, but increased again at 2 h. By contrast, most individuals reported subjective recovery by 15 min to 30 min. It was concluded that there is an underlying effect of motion sickness that sensitizes the response to subsequent motion for a period of at least 2 h. This underlying objective effect can occur in the absence of subjective symptoms, has a slower time course than the subjective recovery from symptoms, and appears to be non-monotonic. © 1997 Elsevier Science Inc.

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Method

Design

Subjects (n = 20) were exposed to 10 nauseogenic motion challenges, at a rate of 2 per day, over a 5-day period, Monday through Friday. The time interval between the end of the first and the start of the second motion challenge of each day was either 15 min, 30 min, 1 h, 2 h.
or 2 h. An approximate 24-h time interval was afforded by comparisons between the first session of each day. The order of presentation of time intervals on days 1 through 4 accorded to a replicated $4 \times 4$ latin square design balanced for carryover, each subject randomly allocated to one of the 4 orders. Day 5 allowed a final 24-h comparison and a repetition of the 2-h time interval.

Subjects

Subjects ($n = 20$) were healthy male ($n = 18$) and female ($n = 2$) aircrew referred for airsickness treatment, with intact vestibular function and not under current drug medication (mean age 24.4, SD 2.0 years). Motion Sickness Susceptibility Questionnaire (MSSQ) (7) mean score was 71.15, SD 39.73, corresponding to a percentile mean of 73.9%, SD 23.6%, and indicating that this sample of subjects was more susceptible than the general population, in which the expected mean percentile MSSQ score is 50%. Subjects were fully briefed and free to withdraw at any time. The trial was approved by the appropriate Medical Ethics Committee.

Sickness Ratings and Symptom Scores

During each motion challenge, subjects rated their well-being in response to tape recorded instructions at the start and then every 30 s, on a 1 to 4 sickness scale (1 = OK; 2 = any mild symptoms but no nausea; 3 = mild nausea without other symptoms; 4 = moderate nausea with or without other symptoms; Stop Motion Challenge). In addition, sickness ratings were taken every minute for 5 min, and at 10 min following the motion endpoint. In the rare instances when a subject could not decide whether he was definitely at a specific 1 to 4 sickness rating, half point scoring was allowed. Immediately upon stopping the motion challenge (endpoint), subjects were rated on a symptom checklist for dizziness, bodily warmth, headache, sweating, stomach awareness, increased salivation, nausea, pallor, any other symptom(s) (symptom scoring: nil = 0, mild = 1, moderate = 2, severe = 3). The aggregated score of the symptom checklist was taken as the "Total Symptom Score," which can vary between a minimum of zero and a theoretical maximum score of 24, excluding "any other symptom(s)."

Motion Stimulus

Subjects were seated upright on an enclosed chair mounted on a turntable; eyes were open. The chair rotated about a vertical axis. For each subject, the direction of rotation was the same across motion challenge sessions, and subjects were randomly allocated to clockwise or counterclockwise directions. A staircase profile of rotational velocity was employed that incremented from $4^\circ$ to $92^\circ.s^{-1}$ in steps of $4^\circ.s^{-1}$ every half minute. Subjects performed a sequence of head movements to the left, right, back, and forward in a random order determined by tape-recorded instructions. Eight head movements of approximately $45^\circ$ to head stops were completed every 30 s, at the end of which subjects rated their malaise level. The motion challenge was stopped immediately upon reaching a sickness rating 4 (moderate nausea).

The advantage of a ramp (staircase) rotational velocity profile as opposed to constant profile is that the ramp profile has sufficient stimulus range to provide an adequate stimulus across the naturally occurring wide individual differences in susceptibility. By contrast, a constant profile would require extensive pretesting for each subject to gauge a suitable level of rotational velocity for that subject, which would also be reliable across some 10 further motion challenge repetitions. Thus, with a too strong stimulus the exposure times would be so short as to cause measurement difficulties; with too weak a stimulus the subject would not achieve a motion endpoint of moderate nausea.

Procedure

Motion challenges were performed in the mornings between 0830 and 1200, Monday through Friday. In the 5-min period following the end of the challenge, subjects were required to lie still on a recovery couch. This was to stan-
Standardize conditions between subjects and across sessions, since movement activities, such as walking around, especially in the first few minutes after a motion challenge, can exacerbate subjective symptoms.

**Data Analysis**

ANOVA was performed on the balanced design for days 1 through 4, and also unbalanced ANOVA was performed on days 1 through 5. Since the conclusions drawn from these analyses were the same, for brevity only the unbalanced presented. The ANOVA design was an omnibus 5-way unbalanced session nested under time interval, and also session nested under day of week, where subject was a random effect, and where degrees of freedom for some tests will differ from those expected for a balanced design because of the inclusion of data from the extra session for the 2-h interval on day 5. For Newman–Keuls tests and t tests with Bonferroni bounds, the probabilities quoted were after the relevant adjustments had been made. The ANOVA factor labels were as follows: DAY (5 days, Mon–Fri); FIRST (first and second sessions of each day); TIME (time interval between the first and second sessions of each day); ORDER (order in which the subjects experienced the time intervals). The factor label RECOVER applied only to analysis of sickness, rating recovery from 1 to 10 min after motion endpoint. Despite the ordinal nature of the data, ANOVA was considered appropriate for analysis of sickness ratings, since the underlying dataset was approximately normal (8). We undertook a Box-Cox maximum likelihood test on the dataset, and no transformation (reciprocal, log, square-root, etc.) could be identified that would improve the normality of the dataset. This supported the hypothesis that the underlying structure of the dataset was approximately Gaussian. The specific contrasts used to isolate the source of effects were t tests with Bonferroni bounds and Newman–Keuls tests.

A “Stimulus Dose” can be calculated that takes into account the greater motion stimulus provided when head movements are made at higher rotational velocities (9). For a linear ramp profile incrementing from zero rotational velocity to the maximum of $92^\circ.s^{-1}$ at $\Delta \theta_s$ per sequence of head movements, where head movements are made at the rate of one sequence of 8 head movements per half minute, where $\Delta \theta$ is the number of sequences of head movements completed, and inserting $\Delta \theta_s = \Delta \theta_s$ as $a \cdot s^{-1}$ then Stimulus Dose $= (\Delta \theta/6) (\text{seq}(\text{seq}+1))/2$. We performed the relevant calculations, and since there were no significant changes in the conclusions, for brevity, only the analyses based on head movements are presented.

**Results**

**Sickness Ratings**

Sickness ratings over time are shown in Figure 1. Sickness ratings declined rapidly following the endpoint of the motion challenge. By +10 min post motion challenge, subjects were at sickness rating of 1 (symptom-free) in 51% of sessions, with 43% at sickness rating of 2 (mild symptoms, no nausea) and 6% at sickness rating of 3 (mild nausea). These percentages are based on the aggregate of $5 \times 20 = 100$ sessions. Beyond +10 min, fewer recovery data were available as an inevitable consequence of the variable timing interval to the second motion challenge. By +15 min, most individuals were subjectively recovered, only 7/20 experienced symptoms at a sickness rating of 2, and by +30 min, 3/20 reported a sickness rating of 2, and 3/20 a rating of 1.5. All individuals were subjectively recovered, only 7/20 experienced symptoms at a sickness rating of 2, and by +30 min, 3/20 reported a sickness rating of 2, and 3/20 a rating of 1.5. All individuals were subjectively recovered (sickness rating of 1) at 0 min, 120 min, and 24 h. ANOVA performed on recovery +10 to +10 min indicated that these declines in sickness ratings were highly significant (RECOVER: $F = 120.2$, df 5,95, $P < 0.0001$). There were no significant effects or interactions for FIRST, TIME, ORDER, or DAY.

**Total Symptom Scores at Motion Endpoint**

Total symptom scores at motion endpoint remained constant over the course of the 5-day
Grand Mean Sickness Rating

Figure 1. Sickness ratings (1 = OK to 4 = Moderate Nausea) are shown over time, for the first and second of each pair of motion challenges (semilog plot). Time zero is at the motion endpoint at sickness rating of 4. Continuation points at 2 h and 24 h are sickness rating = 1 (not shown). The means are grand averages: from 0 to 10 min each point is the mean of 100 observations, and from 15 min onwards each point is the mean of 20 observations.

period from day 1 (mean total symptom score 12.8) to day 5 (mean total symptom score 12.0) and were similar between first (mean total symptom score 12.3) and second (mean total symptom score 12.4) motion challenges, with no significant effects or interactions for DAY, FIRST, TIME, or ORDER.

Motion Tolerance (sequences of head movements)

The number of head movements tolerated before achieving sickness ratings of 2, 3, or 4 increased over the 5 days of motion challenge sessions (Figure 2). This increase, which represents habituation, was significant for sickness rating 2 (DAY: linear effect $F_{20.9, 1,72} = 20.9, P < 0.0001$), sickness rating 3 (DAY: linear effect $F_{18.6, 1,72} = 18.6, P < 0.0001$), and sickness rating 4 (DAY: linear effect $F_{17.7, 1,72} = 17.7, P < 0.0001$). The effects for the first versus second motion challenge of each day were significant for sickness rating 2 (FIRST: $F_{32.7, 1,19} = 32.7, P < 0.0001$), for sickness rating 3 (FIRST: $F_{61.4, 1,19} = 61.4, P < 0.0001$), and sickness rating 4 (FIRST: $F_{41.7, 1,19} = 41.7, P < 0.0001$). Examination of the means (Figure 2) and linear contrasts indicated that the source of the FIRST effect was the drop in motion tolerance in the second of each pair of challenges. The interaction FIRST × TIME was significant for sickness rating 2 (FIRST × TIME: $F_{8.7, 4,76} = 8.7, P < 0.00005$), for sickness rating 3 (FIRST × TIME: $F_{6.8, 4,76} = 6.8, P < 0.0001$), and for sickness rating 4 (FIRST × TIME: $F_{6.4, 4,76} = 6.4, P < 0.00005$). Effects for TIME were significant for sickness rating 2 (TIME: $F_{5.3, 4,72} = 5.3, P < 0.0001$), for sickness rating 3 (TIME: $F_{3.3, 4,72} = 3.3, P < 0.05$), and for sickness rating 4 (TIME: $F_{2.9, 4,72} = 2.9, P < 0.05$). Effects for ORDER, DAY, and other interactions were not significant.

Examination of the means and linear contrasts indicated that the source of the FIRST ×
TIME interaction was the effect of the different time intervals between the first and second motion challenges. The difference between the first and second motion challenge, labeled "loss of tolerance," is shown as a function of time interval between them (semilog plot, Figure 3). Significance levels in Figure 3 refer to first versus second motion challenge contrasts. The loss of tolerance decreased to nonsignificance at 1 h, but then rose again at 2 h, as a function of the time interval between the first and second challenges. Over the 24-h interval between the first session of each day and the first session of the next day, the mean difference showed a negative loss of tolerance, that is, a tolerance gain representing habituation.

Since some subjects exhibited residual subjective symptoms at 15 and 30 min, these subjects were eliminated and the analyses repeated. This was to ascertain whether the reduction in motion tolerance at 15 min, 30 min, and 2 h was observable in subjects who were entirely free from subjective symptoms. The reductions in tolerance remained of similar magnitude and still retained significance (0.001 < $P$ < 0.05), albeit at significance levels somewhat reduced by the diminished number of subjects. Finally, the data were analyzed to examine whether the time interval of rechallenge affected 24-h habituation, and no significant effects were found.

**Time Constants for Subjective and Objective Recovery**

Nonlinear regression was used to obtain values of the time constants for subjective (sickness rating scale) and objective (loss of tolerance as seqs. head movements) recovery following the end of the motion challenge. The data were analyzed using an iterative method (Newton-Raphson). For subjective recovery, the time period up to +10 min post motion challenge was utilized, since this contained the majority of the variation and of observed values. Various mathematical models were employed of the form

$$\text{sickness rating} = a + b \cdot e^{-c \cdot t}$$

where $a$, $b$, and $c$ are constants, and $t$ is time in minutes. The most satisfactory model was
achieved by forcing the value of the constant $a$ to be 1, which implies that there is full recovery at $t$ equals infinity, and including time zero as sickness rating of 4. These curve fits accounted for approximately 80% to 85% of the variance. The most reasonable fit to the data was then of the form:

$$\text{Sickness Rating} = 15.926 \cdot e^{-0.0685 \cdot t}$$

which gives a Time Constant of around 4 min for subjective recovery. For the 0 to 5- or 0 to 10-min periods post motion challenge, there was no evidence to justify a more complex double exponential (two time constant) model.

By contrast, a two consecutive exponential model seemed justifiable only when the very limited data out to 60 min were used, that is, based on fewer observations and with very few people even slightly nauseous at these longer times. If a second line was fitted from 10 min to 60 min, it appeared as though there was a "break" between 5 and 10 min (see Figure 1). This may have been due to an effect of subject locomotion away from the recovery couch after 5 min. Indeed this seemed a reasonable conjecture for what appeared to be a different process starting after this time. However, it must be re-emphasized that the data beyond 10 min were limited for the reasons given above.

The objective recovery was analyzed as the difference between the first and second motion challenges in terms of the number of sequences of head movements to a reach sickness rating of 4, by time interval between motion challenges. Since there was a significant reversal at 2 h (see Figure 3), only the 15-min, 30-min, and 1-h intervals were utilized. An exponential fit gave an equation of the form:

$$\text{loss of tolerance} = 15.926 \cdot e^{-0.0685 \cdot t}$$
in seqs of head movements, where \( t \) is time in min from motion endpoint. The Time Constant for objective recovery is thus around 15 min. This model predicts a loss of tolerance of 16 seqs of head movements at \( t = 0 \) for sickness rating 4. It can be asserted that if a second motion challenge were to start at \( t = 0 \) when sickness rating is 4, then the loss of tolerance would be total, equivalent to number of head movement seqs made in the first motion challenge. This averaged around 24 seqs.

Discussion

The aim of the study was to determine whether the time-course of objective recovery of tolerance, as assessed by rechallenge with motion, paralleled the subjective recovery from motion sickness. Most individuals had recovered subjectively by 15 min, and all had done so by 1 h and onwards. By contrast, objective recovery of tolerance assessed by rechallenge was slower; the loss of tolerance was maximal at 15 min. These results may provide an explanation for ‘sudden emesis’ in parabolic flight experiments where some subjects, who are symptom-free in terms of recovering from an experimental session, may nevertheless experience sudden nausea and vomiting due to the vestibular stimulus caused on the aircraft landing (10). Similar observations have been made in space flight, namely, occasionally an astronaut seems symptom-free and then with a sudden head movement may experience virtually instant nausea. (Lackner, personal communication, 1995).

Habituation to the motion occurred over the course of the study. If this is taken into account, then the loss of tolerance would be larger than the difference between initial and retest values shown in Figure 3, since a small gain in tolerance, due to habituation, should be expected in the second of each pair of motion challenges. Data from other experiments in this laboratory (3) indicate that the average habituation rate that might be expected is about 0.5 to 1 sequences of head movements per motion challenge session, when sessions are repeated at approximately 6-h intervals. The 24-h habituation data in this experiment are consistent with this, if modified by a factor of 0.5 to correct for what is, in effect, an extra session (the rechallenge) interpolated between the initial and the 24-h sessions.

It should be noted that the magnitude of the 24-h habituation was unaffected by whether the intervening motion session was a 15-, 30-, 60-, or 120 min rechallenge. This finding could be of practical importance to motion sickness desensitization when logistics dictate that aircrew cannot receive their motion sessions at the longer time intervals usually employed (2,3).

A feature of the objective recovery was that after an exponential recovery from 15 min to 1 h, loss of motion tolerance rose again significantly at 2 h. A time of day effect is made unlikely by the variation of start times for each pair of challenges. There are few models of motion sickness recovery, reflecting the paucity of systematic experiments directed towards this area. The model of Oman (1) was based on 3 successive 10-min challenges (Coriolis stimulation or the wearing of L–R image inverting goggles) with 5-min intervals over a total time period of 45 min. His model contains two parallel pathways of fast (time constant 1 min, perhaps neuronal) and slow (time constant 10 min, perhaps neurohumoral) responses, which summate. While the results up to 60 min in the present experiment accord in general terms with the Oman model, the observations at 2 h require further explanation. It is possible that the longer-term dynamics of recovery are non-monotonic as a consequence of some slow oscillation in a neurohumoral system due to the perturbation caused by motion sickness. Although not observed in this experiment, a few subjects in this laboratory have spontaneously commented that motion sickness symptoms have recurred several hours after they thought they had recovered, a finding reminiscent of so-called “flashbacks” of simulator sickness symptoms (11).

Alternatively, an over-compensation may occur in the resetting to the normal world of the
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Altered neural relationships between visual/visceral/somatic systems produced by adaptation to cross-coupled motion. We cannot discount the possibility that the loss of tolerance at 2 h was provoked by increased physical activity acting on altered sensorimotor relationships, a short-term mal-de-debarquement (7). However, a mal-de-debarquement explanation is made somewhat unlikely at 2 h since such an effect is more likely to occur at 5 to 10 min when subjects were then free to move around from the recovery couch.

Two caveats may be made concerning this study. First, since the motion endpoints were of moderate nausea, it is possible that with more severe nausea and/or vomiting, the time course of recovery may be somewhat different. Although the recovery time course would be most probably extended following more severe motion sickness, anecdotaly, some individuals claim that they feel immediate relief following vomiting, although this may be temporary and then symptoms often return. Second, it should be noted that this subject sample was drawn from the more motion susceptible portion of the population, and therefore caution must be exercised in generalizing to the whole population.

In conclusion, it appears that there is an underlying effect of motion sickness that sensitizes the response to subsequent motion for a period of at least 2 h. This underlying effect has a slower time-course than the subjective recovery from symptoms and may be non-monotonic.

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REFERENCES