The Effect of Mild Motion Sickness and Sopite Syndrome on Multitasking Cognitive Performance

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Objective: In this study, we investigated the effects of mild motion sickness and sopite syndrome on multitasking cognitive performance.

Background: Despite knowledge on general motion sickness, little is known about the effect of motion sickness and sopite syndrome on multitasking cognitive performance. Specifically, there is a gap in existing knowledge in the gray area of mild motion sickness.

Method: Fifty-one healthy individuals performed a multitasking battery. Three independent groups of participants were exposed to two experimental sessions. Two groups received motion only in the first or the second session, whereas the control group did not receive motion. Measurements of motion sickness, sopite syndrome, alertness, and performance were collected during the experiment.

Results: Only during the second session, motion sickness and sopite syndrome had a significant negative association with cognitive performance. Significant performance differences between symptomatic and asymptomatic participants in the second session were identified in composite (9.43%), memory (31.7%), and arithmetic (14.7%) task scores. The results suggest that performance retention between sessions was not affected by mild motion sickness.

Conclusion: Multitasking cognitive performance declined even when motion sickness and sopite syndrome had a significant negative association with cognitive performance. Significant performance differences between symptomatic and asymptomatic participants in the second session were identified in composite, memory, and arithmetic tasks. The results suggest that performance retention between sessions was not affected by mild motion sickness.

Application: Even mild motion sickness has potential implications for multitasking operational performance.

Keywords: cognitive multitasking performance, motion sickness, sopite syndrome, stress, cognitive resources

INTRODUCTION

Motion sickness in healthy individuals is a common syndrome that occurs when people are exposed to real or apparent motion with which they are unadapted. Susceptibility to motion sickness has been linked to age, personality traits, and past sensory experiences (Benson, 2002; Gordon et al., 1994). However, research provides mixed results as to the effect of gender (Benson, 2002). The signs and symptoms of motion sickness include breathing irregularities, yawning, sweating, disorientation, drowsiness, apathy, facial pallor, cold sweating, nausea, and emesis (Benson, 2002). It was not until 1976 that Graybiel and Knepton changed the perspective by defining “sopite syndrome.” The term describes a symptom complex centering on drowsiness and lethargy related to motion sickness. Sopite syndrome is associated with drowsiness, yawning, disinterest and disinclination to work, lack of participation in group activities, mood changes, sleep disturbances, and mild depression. Depending on the susceptibility of the individual and the motion stimulus, sopite syndrome may be the only reported manifestation of motion sickness (Graybiel & Knepton, 1976; Mead & Lawson, 1997).

The most widely accepted theory regarding the causal factors of motion sickness has several names: sensory conflict mismatch theory, sensory rearrangement theory (Reason & Brand, 1975), or neural mismatch theory (Benson, 1999). In general, this theory postulates that the cause of motion sickness is the mismatch between the pattern of information from the spatial senses and that retained in memory of previous experience. In contrast to the sensory conflict theory, the postural instability theory was proposed (Riccio & Stoffregen, 1991; Stoffregen & Riccio, 1991). Based on an ecological perspective, the main hypothesis of this theory is

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that animals become sick in situations in which
they do not possess (or have not yet learned)
strategies that are effective for the maintenance
of postural stability. Therefore, motion sickness
may result from prolonged instability in the con-
trol of posture. Later experimental results
showed that postural sway precedes the onset of
subjective motion sickness symptoms, which is
a key prediction of the postural instability theory
of motion sickness (Stoffregen & Smart, 1998).

Furthermore, there is a long discussion regard-
ing the relationship between motion sickness and
cognitive resources, with analogous ideas tracing
back to Teichner’s “distraction principle” (Ken-
nedy et al., 1987, p. 11; Teichner, 1958). Investig-
gating the effect of cold on cognitive performance,
Teichner (1958) hypothesized that the physiologi-
cal stress induced by cold causes mental distrac-
tion, which subsequently degrades cognitive
performance. Motion sickness may distract per-
formance in a similar way by increasing stress.
Later research provided some experimental vali-
dation of the assertion that motion sickness inter-
feres with cognitive resources. Postural control is
not an entirely automated process. Attentional
resources that could otherwise be diverted to cog-
nitive functions are allocated to functions such as
controlling body sway and to accurately monitor-
ing changes in bodily orientation (Andersson,
Hagman, Talianzadeh, Svedberg, & Larsen, 2002;
Talkowski, Redfern, Jennings, & Furman, 2005).
However, an opposing relationship also has been
identified. Evidence suggests that being involved
with a mental task may decrease the severity of
motion sickness (Bos, 2011).

Research also has addressed the effects of
motion sickness on cognitive performance, but
results are inconclusive (Hettinger, Kennedy, &
McCauley, 1990). Some studies did not identify
any significantly deleterious effects (Bos,
MacKinnon, & Patterson, 2005). Other studies,
though, showed that motion sickness reduces
performance (Baker, 1966; Valk, Munnoch, &
Bos, 2008). Detrimental effects have been
observed in short-term memory (Bos, 2011;
Dahlman, Sjörs, Lindström, Ledin, & Falkmer,
2009), in command-and-control tasks (Cowings,
Toscano, DeRoshia, & Tauson, 2001), and in
visual search (Golding & Kerguelen, 1992).

The beneficial effect of motivation and task
involvement in reducing motion sickness has
been noted. Anecdotal data and subjective
reports since World War II suggest that even sick
individuals can continue performing acceptably
if highly motivated (Baker, 1966), and encour-
agement to suppress symptoms increases toler-
ance (Dobie & May, 1994). Last, we failed to
identify any studies exploring the effects of
motion sickness on practice effects, learning/
skill acquisition, and reminiscence, that is, per-
formance improvement of a partially learned
task in the absence of actual practice (Eysenck
& Frith, 1977, p. 3).

This review reveals a number of points that
either provide insight or lead to concern: (a)
Cognitive performance is not affected by motion
per se (Wertheim, 1996, 1998); (b) earlier
research regarding motion sickness effects on
cognitive performance provides valuable insight
but in many cases fails to provide conclusive
results because of three methodological issues:
nonstabilized performance (practice effects),
lack of a control group, and use of a control
group whereby participants perform in static
conditions (Wiker & Pepper, 1978); (c) it is gen-
erally accepted that severe motion sickness will
lead to performance decrements or cessation of
performance, possibly due to reduced motiva-
tion; (d) there is a lack of adequate research in
the assessment of the effects of motion sickness
per se on multitasking cognitive performance;
and (e) there is a gap in the experimental assess-
ment and quantification of the effects of mild
motion sickness and sopite syndrome on cogni-
tive performance.

Given the aforementioned gaps in research,
this study focused on this gray area of mild
motion sickness, whereby some symptoms exist
but the severity of malaise is low. In this study,
the term mild motion sickness is used to describe
those motion sickness–related symptoms that
are not incapacitating; the individual is not expe-
riencing moderate or severe malaise and contin-
ues performing the assigned task. This study
assessed in controlled conditions the hypothesis
that multitasking cognitive performance is sig-
ificantly reduced by mild motion sickness and
soporific effects.
Method

Participants

Fifty-one healthy participants from the Naval Postgraduate School (NPS; 45 males and 6 females; age, $M = 35.4$ years, $SD = 5.74$) volunteered for the study after responding to an e-mail advertisement. Informed consent was obtained after the experimental procedures had been fully explained. The study protocol was approved by the NPS Institutional Review Board.

Apparatus and Measurements

Motion was produced by the ASE Model 500–3 motion seat manufactured by Aeronautical Systems Engineering, Odessa, Florida. The nauseogenic motion stimulus included the superposition of three independent 0.167 Hz sinusoidal motions with $\pm 2$ inches heave and $\pm 15^\circ$ roll and pitch. During data collection, participants use a mouse to perform SYNWIN™ (Activity Research, Inc.) multitasking battery, the Windows version of SYNWORK1 (Elsmore, 1994). It includes four component tasks presented simultaneously: a memory search task, an arithmetic problem task (the only self-paced task in the battery), and two visual and auditory reaction tasks. The screen is divided into quadrants, each one allocated to a task (Figure 1).

At the beginning of a memory task session, a list of five letters is shown for 5 s. After the letters are erased, a letter is displayed for 20 s. The participant responds to indicate whether the displayed letter was a member of the initial set of letters. Points are gained for a correct response, whereas points are lost with incorrect responses or whenever the participant decides to see again the initial letter list. In the self-paced arithmetic task, participants sum two three-digit numbers. New numbers appear only after the participant responds. Points are added for a correct sum or subtracted for an incorrect sum. In the visual monitoring task, a meter-style pointer moves at a fixed rate from right (100 position) to left (0 position) across a gauge. Participants must prevent the pointer from reaching 0 by clicking on the gauge to reset the pointer to the 100 position. More points are received for the pointer being as close to 0 as possible, and points are lost for every second the pointer stays at 0. In the auditory task, every 5 s, participants must respond to...
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a 1025 Hz “positive” tone and ignore a 1000 Hz “negative” tone. Points are awarded to correct detections, whereas points are subtracted on erroneously detecting the positive or negative sounds. The probability of a positive tone was 20%. The rest of SYNWIN functional parameters were set at their default values.

The four generic SYNWIN tasks address known cognitive resources and constitute a basis for the cognitive tasks commonly found in various work environments and occupations (Proctor & Wang, 1998). The memory and the arithmetic tasks are associated with working memory capacity (Raghubar, Barnes, & Hecht, 2010). Being primarily perceptual, the visual and auditory monitoring tasks occur in different sensory modalities and assess distinct attentional resources (Wickens, 1980, 2002).

Participants wore headphones for the auditory stimuli, and SYNWIN was projected on the eMagin Z800 3DVisor Head Mounted Display (HMD). The apparatus provides approximately 40° diagonal field of view in two displays with 4:3 aspect ratio. The resolution was 800 × 600 pixels per display (SVGA).

Susceptibility to motion sickness was assessed by the revised version of the Motion Sickness Susceptibility Questionnaire (MSSQ; Golding, 1998), whereas severity of symptoms was assessed by the Motion Sickness Assessment Questionnaire (MSAQ; Gianaros, Muth, Mordkoff, Levine, & Stern, 2001). The MSAQ includes four subscales (Gastrointestinal, Central, Peripheral, and Sopite-Related [MSAQ S]). The linear combination of the four subscales leads to the MSAQ total score.

Procedures

The experiment was conducted at the NPS in three data collection periods (2010, 2011, and 2012). Initially, participants completed the screening questionnaire followed by the demographics questionnaire. The screening instrument included questions regarding recent surgeries, sleep and vestibular disorders from the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10), and the use of medication.

Participants performed the SYNWIN individually with the single objective to obtain as many points as possible and therefore increase the component score. Each individual participated in two 1-hr data collection periods (experimental sessions [ES]) with an intersession interval of 7 days ($M = 6.61, SD = 1.28$). The physiological state of the participants was assessed before each ES by a survey instrument that included the Epworth Sleepiness Scale, the SSS, and survey questions about participants’ health (state of fitness, illness, medication reception, consumption of alcohol). Each ES consisted of six 10-min blocks, for a total of 60 min. After each block, participants responded to the MSAQ and the SSS. None of the participants had prior experience with SYNWIN. They received approximately 2 to 3 min of initial practice to learn the basics of the tasks (the displays, the controls, and the procedures associated with using SYNWIN).

Participants from 2010 and 2011 data collection sessions were randomly assigned to one of two groups: M-NM, for the sequence “motion—no motion,” and NM-M, for the sequence “no motion—motion” (Figure 2). Within each ES, the motion stimulus was presented from the start of the third SYNWIN block till the end of the ES. All participants from the 2012 data collection were assigned to a control group, NM-NM, and did not experience motion in either session. Participant groups were demographically homogeneous in age, gender, height, weight, MSSQ ratings, and the time of day the session started (Wilcoxon rank sum test, $p > .05$).

Participants completed a sleep log starting approximately 3 days before the first ES and continued until the end of the last ES. Participants were instructed not to use alcohol during the day before the ES and to avoid it during the remainder of the study. After each 10-min SYNWIN block, participants provided a subjective evaluation of their physiological state by responding to the MSAQ and the SSS.

The experimenter was located in the same room with the participant. Both ESs were conducted at the same time of day for each participant.
to control for circadian rhythmicity. Participants did not receive visual or auditory input from the external environment because they wore the HMD, the room was nearly dark, and they wore headphones.

**Analytical Plan**

The statistical equivalence between the three participant groups was assessed, including age, gender, height, weight, MSSQ ratings, and the time of day the session started. Then, we assessed the effect of motion sickness on performance. Within each motion session, two analysis methods were used. First, a correlational analysis was conducted between the average performance scores of each participant with the corresponding average motion sickness severity. Second, there was a comparison of performance scores between the symptomatic and the asymptomatic participants. The basis of participants’ classification into the two motion sickness groups (symptomatic, asymptomatic) was to compare each participant’s average symptom severity for both the motion and static conditions. If symptom severity in motion was greater than in the static condition, the participant was classified as “symptomatic.” If motion sickness severity was less than or equal to the static condition, the participant was classified as “neutral.” Participants without symptoms in both static and motion conditions were classified as “asymptomatic.” In the first motion session (M-NM group, \( n = 20 \)), there were 10 symptomatic, 2 neutral, and 8 asymptomatic participants. In the second motion session (NM-M group, \( n = 19 \)), there were 11 symptomatic, 1 neutral, and 7 asymptomatic participants.

Last, the effect of motion sickness on between-session performance changes was assessed using repeated-measures ANOVA with a between-subjects factor, participant’s grouping.

Microsoft Office Excel 2007 was used to develop the initial study databases. Analyses were conducted with JMP® Pro 9.0.0 by SAS Institute. Data normality was evaluated using the Shapiro-Wilk \( W \) test. Parametric and nonparametric approaches were used accordingly for statistical analyses. In the repeated-measures ANOVA, sphericity was tested with Mauchly’s test. When appropriate, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity.

SYNWIN performance scores were transformed by a normalization method, independently for each participant. Two forms of the normalized scores were used. For each participant, the intrasession score (henceforth referred to as INTRA) was calculated over each 10-min block using the following equation: \( \text{INTRA}_i = \frac{\text{absolute value of the metric}}{\text{average value of the metric in the first two 10-min blocks of the corresponding } i\text{th ES}} \). The intersession form (henceforth referred to as INTER) was the same as the INTRA form, but the normalization was performed using the first two 10-min blocks of the corresponding \( i\text{th ES} \).
blocks of the first session as the baseline for normalization.

The independent variables were motion (vs. no motion), ES (first, second), and 10-min block rank (first, second, etc.). Motion sickness severity (MSAQ total and MSAQ S scores) were used as ad hoc “independent” variable. SYNWIN composite and task scores (memory, arithmetic, visual detection, auditory detection) were the dependent variables.

RESULTS

The MSSQ average of our population was 15.3, much lower than the 50th percentile (which is at an MSSQ score of approximately 40). This result suggests that the average susceptibility was lower than that of a normal population. The MSAQ includes 16 symptoms. At the end of each 10-min block, participants rated the severity of each one of these symptoms. All 16 symptoms were reported at least once in motion conditions, whereas only 6 of the 16 symptoms were reported during exposure to the static condition. Compared to the static condition, the severity of motion sickness and soporific symptoms increased in motion (Table 1). Furthermore, the severity of motion sickness was statistically equivalent between Motion ES 1 and Motion ES 2 (Wilcoxon rank sum test, \( p > .10 \)). In motion conditions, the average MSAQ total for all participants was 14.4 (SD = 6.35). Given that the MSAQ total scale ranges from 11.1 (no symptoms) to 100, the average severity of symptoms in our experiment suggests a mild malaise.

After the end of each session, participants were asked whether they experienced any problems while performing SYNWIN, including the use of the HMD, but no problems were reported. More importantly, the MSAQ responses do not suggest that the use of the HMD systematically biased our results; 71% of the participants in static conditions and 60% in the motion conditions did not report any of the 16 MSAQ symptoms included in the MSAQ. Last, it should be noted that most of our participants were active-duty military officers and already had experience with HMDs. All these items suggest that there was no systematic bias introduced from the use of the HMD.

Motion Sickness, Performance, and the Differential Effect of Session

This section explores two issues: the effect of motion sickness and sopite syndrome symptoms on SYNWIN scores and the order effect associated with the ESs. First, a correlational analysis (Spearman’s rho) was performed between SYNWIN scores (INTRA) and the subjective metrics of motion sickness (MSAQ S and SSS) in motion conditions. All values were averaged per participant and motion ES. The analysis focuses on motion conditions with participant groups M-NM and NM-M. Results showed (Table 2) that the composite, the memory task, and the arithmetic task scores decreased when motion sickness and soporific severity increased but only in ES 2. No significant associations were identified for the visual and auditory tasks in both sessions.

No significant correlations were identified in the static conditions. Next, we assessed in motion conditions whether symptomatic participants demonstrated reduced performance when compared to asymptomatic participants. Although motion sickness severity did not differ between motion sessions, Wilcoxon rank sum test, \( \chi^2(1) = \)
In a comparison between the asymptomatic group (in motion) and participants in the (static) control group, we did not identify any significant performance differences (Wilcoxon rank sum test, \( p > .05 \)). This result suggests that motion did not interfere biodynamically with performing SYNWIN.

### The Effect of Motion Sickness on Performance Differences Between ESs

In this section, we assess the differences in performance between ESs in association with the presentation of motion and the development of motion sickness symptoms. First, analysis was focused on performance changes from the end of the first ES (Block 6) to the beginning of the second ES (Block 7). In a within-subject ANOVA between Blocks 6 and 7 with a between-subjects factor (five participant groups: symptomatic in M-NM group, asymptomatic in M-NM group, symptomatic in NM-M group, asymptomatic in NM-M group, symptomatic in MNM group), we did not identify any significant performance differences (Wilcoxon rank sum test, \( p > .05 \)). This result suggests that motion did not interfere biodynamically with performing SYNWIN.

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**Table 2: Associations Between SYNWIN Performance Scores (INTRA) and Motion Sickness Severity**

<table>
<thead>
<tr>
<th>Score</th>
<th>ES 1 in Motion Group M-NM</th>
<th>ES 2 in Motion Group NM-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>—</td>
<td>MSAQ total (( \rho = -0.726, p &lt; .001 ))*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSAQ S (( \rho = -0.606, p = .006 ))*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSS (( \rho = -0.472, p = .042 ))*</td>
</tr>
<tr>
<td>Memory task</td>
<td>—</td>
<td>MSAQ total (( \rho = -0.545, p = .016 ))*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSAQ S (( \rho = -0.475, p = .040 ))*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSS (( \rho = -0.483, p = .036 ))*</td>
</tr>
<tr>
<td>Arithmetic task</td>
<td>—</td>
<td>MSAQ total (( \rho = -0.600, p = .007 ))*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSAQ S (( \rho = -0.481, p = .037 ))*</td>
</tr>
<tr>
<td>Visual task</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Auditory task</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Note.* MSAQ = Motion Sickness Assessment Questionnaire (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001); MSAQ S = MSAQ Sopite-Related subscale; SSS = Stanford Sleepiness Scale (Hoddes, Dement, & Zarcone, 1972).

**Table 3: SYNWIN (INTRA) Score Differences Between Symptomatic/Asymptomatic Individuals by Motion Experimental Session (ES)**

<table>
<thead>
<tr>
<th>Score</th>
<th>Motion ES</th>
<th>Asymptomatic % M (SD)</th>
<th>Symptomatic % M (SD)</th>
<th>Significance (Wilcoxon Rank Sum Test)</th>
<th>Hedge's g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>1</td>
<td>123 (12.7)</td>
<td>122 (14.2)</td>
<td>( \chi^2(1) = 0.097, p = .755 )</td>
<td>0.070</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>113 (6.17)</td>
<td>103 (10.1)</td>
<td>( \chi^2(1) = 6.47, p = .011 )*</td>
<td>1.08</td>
</tr>
<tr>
<td>Memory</td>
<td>1</td>
<td>141 (33.8)</td>
<td>172 (142)</td>
<td>( \chi^2(1) = 0.387, p = .534 )</td>
<td>0.271</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>138 (52.2)</td>
<td>105 (12.5)</td>
<td>( \chi^2(1) = 3.81, p = .050 )*</td>
<td>0.939</td>
</tr>
<tr>
<td>Arithmetic</td>
<td>1</td>
<td>139 (27.9)</td>
<td>134 (33.6)</td>
<td>( \chi^2(1) = 0.008, p = .929 )</td>
<td>0.153</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>117 (11.4)</td>
<td>102 (22.5)</td>
<td>( \chi^2(1) = 5.33, p = .021 )*</td>
<td>0.748</td>
</tr>
<tr>
<td>Visual</td>
<td>1</td>
<td>96.3 (4.03)</td>
<td>97.1 (4.28)</td>
<td>( \chi^2(1) = 0.244, p = .626 )</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>98.5 (2.94)</td>
<td>97.9 (2.70)</td>
<td>( \chi^2(1) = 0.033, p = .855 )</td>
<td>0.205</td>
</tr>
<tr>
<td>Auditory</td>
<td>1</td>
<td>114 (24.6)</td>
<td>118 (24.4)</td>
<td>( \chi^2(1) = 0.641, p = .423 )</td>
<td>0.155</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>108 (11.5)</td>
<td>106 (11.5)</td>
<td>( \chi^2(1) = 0.741, p = .389 )</td>
<td>0.166</td>
</tr>
</tbody>
</table>

\( p < .05 \).

0.144, \( p = .705 \), performance of symptomatic participants was significantly reduced compared to asymptomatic participants only in the second motion ES. These findings are demonstrated in Table 3 and further depicted in Figure 3. A single asterisk indicates \( p < .05 \).

In a comparison between the asymptomatic group (in motion) and participants in the (static) control group, we did not identify any significant performance differences (Wilcoxon rank sum test, \( p > .05 \)). This result suggests that motion did not interfere biodynamically with performing SYNWIN.
NM-M group, asymptomatic in NM-M group, NM-NM group), we did not identify performance changes across time, $F(1, 44) = 1.40, p = .243$, or differences between groups (interaction of ES and participant group), $F(4, 44) = 0.863, p = .494$). For all groups, performance did not change at the beginning of ES 2 compared to the end of ES 1.

Further analysis focused on performance improvement from the first ES to the second ES (Blocks 9 to 12). A one-way repeated-measures ANOVA showed a significant interaction between session and group in composite score, $F(4, 44) = 2.94, p = .031$. This interaction was identified between symptomatic participants in group NM-M and participants in group NM-NM, $F(1, 21) = 6.67, p = .017$, but not among the rest of the groups ($p > .500$). These results show that, excluding symptomatic participants in group NM-M in the second ES, all participant groups showed a comparable increase in performance between sessions.

**DISCUSSION**

Our results show that cognitive multitasking performance declines even when motion sickness and soporific symptoms are mild. The results also provide evidence for an order effect, to be discussed later. Performance differences in composite scores (9.43%), as well as in the memory (31.7%) and arithmetic task scores (14.7%), between symptomatic and asymptomatic individuals by motion session.

**Figure 3.** SYNWIN score (INTRA) differences between symptomatic and asymptomatic individuals by motion session.
atic participants were significant but only in the second session, not the first. Therefore, during the first motion session, participants seem to overcome mild motion sickness, whereas during the second motion session, motion sickness symptoms take a toll on performance (Figure 4).

Figure 4 is a conceptual depiction of the initial improvement of performance when initially learning the multitasking environment, followed by a plateau representing a stabilization of performance over time. The introduction of potentially nauseogenic motion further complicates the individual’s performance. Excluding biodynamic effects, performance is influenced by motion sickness and sopite syndrome symptomatology. Focusing on symptomatic individuals, and assuming a continuous nauseogenic stressor, the associated symptomatology will gradually become more severe. In the second session, after an initial period of non-significant effects, performance demonstrated a more rapid deterioration. On the other hand, the performance of asymptomatic individuals did not seem to be affected by the motion per se. From a methodological perspective, this result means that the performance deterioration associated with motion sickness should be assessed as the performance difference between symptomatic and asymptomatic individuals performing under the same motion conditions. A probable explanation for this finding may be found in the level at which mild motion sickness interferes with cognitive performance in the first session, when participants are still novices. A reasonable hypothesis is that novice participants overcome the detrimental effects of mild motion sickness by focusing more on the multiple tasks during the first session because the tasks are novel and interesting.

Motion Sickness as a Stressor

Considering motion sickness as a stressor, our findings may be explained from a perspective of performance under stress. The deterioration of task performance in cognitive tasks (memory and arithmetic) is congruent with stress research (van Hiel & Mervielde, 2007). Simple tasks needing automated responses will suffer less from stress than will complex tasks with underlying cognitive control. A reasonable ordering of the four SYNWIN tasks based on the resources needed would put the arithmetic

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**Figure 4.** Conceptual depiction of multitasking performance versus nauseogenic motion stimulus, motion sickness severity, and experimental session.
task first, followed by the memory task. The nature of the visual and auditory detection tasks in SYNWIN (lack of visual search, easily identifiable signals) locate them closer to being automated, in the sense that they need a minimal amount of resources (Fitts & Posner, 1967).

Why, then, do we observe this deleterious effect of motion sickness on cognitive performance? Is it due to motivation (or lack thereof) or because of changes in resource capacity, such as limitations of working memory?

Our results seem reasonable also from a perspective of attentional capacity overload (Matthews & Desmond, 1995). The arithmetic task suffered the most, followed by the short-term memory task. The visual and auditory tasks did not seem to be affected. This hierarchy is consistent with the multiple resource theory (Wickens, 2002; Wickens & Hollands, 2000), which postulates that the sensory processing of the peripheral visual and auditory systems is relatively resource-free (Wickens & Hollands, 2000). In this case, the reduction of access to attentional resources due to motion sickness will have only a small effect on the visual and auditory tasks. Our results suggest that motion sickness acts like a distraction or a diversion, and therefore, difficulties in focused attention should be considered among the major symptoms in mild motion sickness. As already noted, however, researchers also have identified that being involved with a mental task may decrease motion sickness severity (Bos, 2011). The inverse relationship between motion sickness severity and cognitive effort may be explained from a cognitive resources and cognition control perspective.

Consider the dichotomy of executive versus automatic control on cognition (Anderson, 1996). Executive control, or controlled processing, is an endogenous control of neurocognitive processes to attain a novel or complex goal, whereas automatic control is evident in learned responses (Logan, 1985; Schneider & Shiffrin, 1977). In our experiment, participants developed the strategy to focus on the arithmetic task, a process reflecting the implementation of an executive control of cognitive resources. Practice was accumulated over time, leading to better performance, that is, increased composite score. However, the accumulation of practice leads to more automated responses (Ericsson, Krampe, & Tesch-Romer, 1993) and therefore to the progressive release of attentional resources formerly allocated to the multitasking battery. We postulate that these resources are partially diverted to monitoring the malaise associated with motion sickness. Therefore, motion sickness acts as a distractor by withholding or denying the use of these attentional resources.

In the absence of motion sickness, or in the existence of mild malaise, a task may be performed in the non-overloading zone of available attentional resources. By limiting available capacity, the existence of motion sickness “pushes” the task into the overloaded or near-overloaded zone. The point at which motion sickness starts to cause significant interference seems to be associated with the executive function, noted earlier. It is interesting that Wickens (2002) has identified that multiple resource theory does not address in an adequate manner resource allocation or “engagement.” He noted circumstances where a task demands or attracts so much attention that eventually full attention is given to that task. Consequently, any concurrent tasks are essentially “dropped” (Wickens, 2002, p. 173). He also notes an example for this situation in which cellular phone conversations were so “engaging” that drivers totally neglected aspects of the concurrent driving task, even though the two tasks were quite (but not totally) separate in their resource demands (Strayer & Johnston, 2001; Wickens, 2002).

The association between executive control and motion sickness extends to the individual’s motivation. A novel task may be more interesting and alerting. In this case, an individual is self-motivated to perform the novel task. From an executive function perspective, this increased motivation reflects the allocation of cognitive resources to the task, a process that is reversed when motivation decreases. Consistent with previous findings (Bos, 2011; Correia & Guedry, 1966), this theoretical scheme provides a plausible explanation for why motion sickness’s effects on performance are associated with motivation, task involvement, and task novelty. Our results suggest an inverse relationship between motion sickness effects on performance and the cognitive effort focused on performing a task.

Motion sickness may distract cognitive performance also through another route. It is known
ack that postural control needs attentional resources (Woollacott & Shumway-Cook, 2002) and that disorientation is one of the symptoms associated with motion sickness (Benson, 2002). Individuals with spatial disorientation may redirect cognitive resources from a cognitive task to the control of posture (Gresty, Golding, & Nightingale, 2008; Woollacott & Shumway-Cook, 2002). Consequently, performance can be degraded (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). However, the disorientation explanation contradicts the order effect we identified in our experiment. If this explanation were true, and given that motion sickness severity was statistically equivalent between sessions, we would expect to find a degradation of performance in both motion sessions.

**Study Limitations**

This study has a number of limitations. Most of our participants were military officers and relatively young. The attributes of this group may not be representative of the general population. The participant groups did not have statistically equivalent SYNWIN performance at the outset of the experiment, and performance was increasing in both experimental sessions. For this reason, performance was normalized for each participant. Future research in operational conditions is needed to explore the external validity of our results. Although the four SYNWIN tasks resemble a real operational multitasking environment, it still remains a simulation.

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**KEY POINTS**

- Cognitive multitasking performance declines even when motion sickness and soporific symptoms are mild.
- Mild motion sickness does not interfere with performance improvement of a partially learned task in the absence of actual practice.
- Results suggest an inverse relationship between motion sickness effects on cognitive multitasking performance and the cognitive effort focused on performing a task.

**REFERENCES**


seogenic potential of low-frequency vertical versus horizontal
linear oscillation. *Aviation, Space, and Environmental Medi-
cine, 63,* 491–497.

Gordon, C. R., Ben-Aryeh, H., Spitzer, O., Dowek, I., Gonen, A.,
Melamed, Y., & Shupak, A. (1994). Seasickness susceptibility,
personality factors, and salivation. *Aviation, Space, and Envi-
ronmental Medicine, 65,* 610–614.

sole manifestation of motion sickness. *Aviation, Space, and
Environmental Medicine, 47,* 873–882.

tive impairment by spatial disorientation. *Aviation, Space,
and Environmental Medicine, 79,* 105–111.

and human performance. In G. H. Crampton (Ed.), *Motion and

Hoddes, E., Dement, W. C., & Zarcone, V. (1972). The develop-
ment and use of the Stanford Sleepiness Scale (SSS). *Psycho-
physiology, 9,* 150–151.

and human performance. In G. H. Crampton (Ed.), *Motion and


design of in-car driving enhancement systems. *Le Travail
Humain, 58,* 109–129.

report I: Motion-induced drowsiness and mood changes in an
individual with no other motion sickness symptoms. A case of
“pure” sopite syndrome? *Aviation, Space, and Environmental
Medicine, 68,* 648.

and mathematics: A review of developmental, individual difference,
and cognitive approaches. *Learning and Individual Differences,
20,* 110–133.

SYNWORK1 multiple-task work environment. *Behavior Research
Methods, Instruments, & Computers, 30,* 287–305.

and mathematics: A review of developmental, individual difference,
and cognitive approaches. *Learning and Individual Differences,
20,* 110–133.

Academic Press.

motion sickness and postural instability. *Ecological Psychology,
3,* 195–240.

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Talkowski, M. E., Redfern, M. S., Jennings, J. R., & Furman, J. M.
(2005). Cognitive requirements for vestibular and ocular motor
processing in healthy adults and patients with unilateral vestibular


performance at sea: Effects on vigilance and complex task
Maritime Conference, Sydney, Australia.

problem-solving strategies in the presence of stressors. *Human
Factors, 49,* 1072–1082.

Wertheim, A. H. (1996). *Human performance in a moving envi-
ronment* (No. TM-96-A063). Delft, Netherlands: TNO Human
Factors Research Institute.

gonomics, 41,* 1845–1858.

Wickens, C. D. (1980). The structure of attentional resources. In
R. Nickerson (Ed.), *Attention and performance VIII* (pp. 239–

Wickens, C. D. (2002). Multiple resources and performance pre-

and human performance* (3rd ed.). Upper Saddle River, NJ:
Prentice Hall.

physiology and affective state due to motions aboard a small
monohull vessel: A preliminary study* (No. CG-D-75-78). Wash-
ington, DC: U.S. Coast Guard, Office of Research and
Development.

Woollacott, M. H., & Shumway-Cook, A. (2002). Attention and the
control of posture and gait: A review of an emerging area of

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