Changes in Reaction Times and Executive Decision-Making following Exposure to Waterborne Motion

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A unique mission of the U.S. Marine Corps is the amphibious assault landing. These missions require transportation by small watercraft, exposing Marines to waterborne motion before landing. The timeliness and accuracy of their decisions once the Marines debark may well determine the outcome of an entire operation. This study assesses how warfighters' performance is affected following exposure to waterborne motion in an amphibious vehicle. Sixty-one Marines were evaluated in four conditions: following one, two and three-hour exposures to waterborne motion and following a two-hour period in a stationary vehicle. Testing included performance on an obstacle course, a marksmanship course, and a cognitive test battery. Self-reported motion sickness levels were also assessed. Results showed no differences on the marksmanship and obstacle course performance. However, after two and three hours of waterborne motion exposure, Marines experienced reduced response times and poorer executive decision making as measured using the Automated Neuropsychological Assessment Metric.

INTRODUCTION

In military combat, there is little margin for error; any degradation in performance could have disastrous and deadly consequences. A unique mission of the U.S. Marine Corps is the amphibious assault landing on potentially hostile beaches. Such amphibious missions require transportation by small watercraft, exposing Marines to waterborne motion before they are expected to engage in dangerous and sometimes lethal combat. The timeliness and accuracy of their decisions once they debark may well determine the success of an entire operation. It is critical to know if and how the performance of warfighters is affected following exposure to waterborne motion in an amphibious vehicle.

The effects of motion sickness on human performance have been discussed in a variety of contexts (see Benson, 2002; Bos, 2004; Bos & Bles, 2000; Coady, 2010; Colwell, 1994; Hettinger, Kennedy, & McCauley, 1989; Reason & Brand, 1975, Wertheim, 1998). It has been shown that environmental motion can negatively affect performance due to motion-induced interruptions (MII), motion induced fatigue (MIF) and motion sickness (Graybiel & Knepton, 1976; Hettinger, Kennedy & McCauley, 1989; McCauley, O'Hanlon, Royal, Mackie & Wylie, 1976; Wertheim, 1998). Significant degradations in both cognitive and physiological performance have been seen during exposure to both real and virtual motion. Both laboratory and field studies indicate that environmental motion can specifically cause decreased performance in motor tasks (Crossland & Lloyd, 1993; McLeod et al., 1980; Walker et al., 2007; Wertheim, 1998). Champney and colleagues (2007) have shown that exposure to virtual motion can result in degraded fine motor skills and vestibular after-effects lasting over an hour. Similarly, Muth and colleagues (2006, 2009) have shown that uncoupled motion (real and virtual) negatively affects operator performance both during and post-exposure. Specifically, they found that cognitive after-effects lasted up to four hours post-motion exposure, and that physiological effects lasted up to two hours (Muth, 2009).

However, the after-effects of motion in an amphibious vehicle on human performance, such as that experienced by Marines, are not as clear. There is anecdotal evidence from the Falklands War of 1982 where 560 Scots Guards launched in four landing craft for a 35-mile voyage to Fitzroy Island. The seas were rough and it took seven hours to reach the island. The troops were seasick and soaked to the skin. Once on the beach, they were unable to defend themselves or fight effectively. Fifty-four Scots Guards were killed in action and over 200 were wounded. The surviving troops were unfit to attack their objective (Schrady, 1992).

The goal of this study was to examine the effects of waterborne motion in an amphibious vehicle on both the cognitive and physiological performance of warfighters immediately following waterborne motion exposure. Given that uncoupled motion studies have shown measurable after-effects requiring a 2 to 4 hour time-course for recovery (Muth, 2009), we expected to find similar results after exposure to actual waterborne motion environments.

METHOD

Participants

A total of 61 Marines volunteered to participate in the study. The age range of the participants was 18 to 28 years with a median of 22. Participants were randomly assigned to four squads stratified for motion sickness susceptibility and prior experience in amphibious vehicles.

Measures and Apparatus

Four amphibious vehicles were used as treatment platforms. Susceptibility to motion sickness was assessed by the Motion Sickness Susceptibility Questionnaire – MSSQ (Golding, 1998). The dependent variables were a) the Motion Sickness Assessment Questionnaire (MSAQ) ratings (Gianaros, Muth, Mordkoff, Levine, & Stern, 2001) taken immediately after debarking from the vehicle and again following a one hour recovery period; b) the length of time required to complete the obstacle course, a modification of the US Marine Corps' Load Effects Assessment Program (MC-LEAP) described by Tack, Kelly, Richter, and Bray-Miner, (2012); c) in the marksmanship course, five shots with the Laser Marksmanship Training System (LMTS) converted to a mean radius of impact (MRI - the spread of five shots) measured in millimeters; and d) in the cognitive test, the Switching Task, part of the Automated Neuropsychological Assessment Metric (ANAM-4, 2007), response time and changes in throughput (correct answers per minute).

Procedures

The study used a repeated measures quasi-experimental design with counterbalancing to control for order of exposure. This procedure allowed participants to serve as their own control and partially accounted for time-of-day effects since participants always commenced testing early in the morning and completed testing two to four hours later. Marines were evaluated in four conditions: following one-, two- and three-hour exposures to waterborne motion in an amphibious vehicle and following a two-hour period where participants sat in a stationary amphibious vehicle. Participants received a week of training to reach steady-state performance levels before the two-week testing period commenced.

Figure 1 shows the daily testing procedure. At the beginning of each day, the Marines engaged in five tests, shown on the left side of Figure 1 as Pre-Treatment. Each day, the Marines engaged in one of the four experimental conditions. Duration of waterborne motion, varying from 0 to 3 hours of exposure, was the independent variable and is shown in Figure 1 as Treatment. After exiting from the vehicle following the Treatment phase, participants entered the Post-Treatment and Recovery phases of testing shown on the right side of Figure 1.

The statistical analysis was conducted using repeated measures analysis of variance (ANOVA); tests of multiple comparisons were conducted using the Tukey Honestly Significant Differences (HSD) Test. Confidence intervals were set at 95% (alpha = .05).

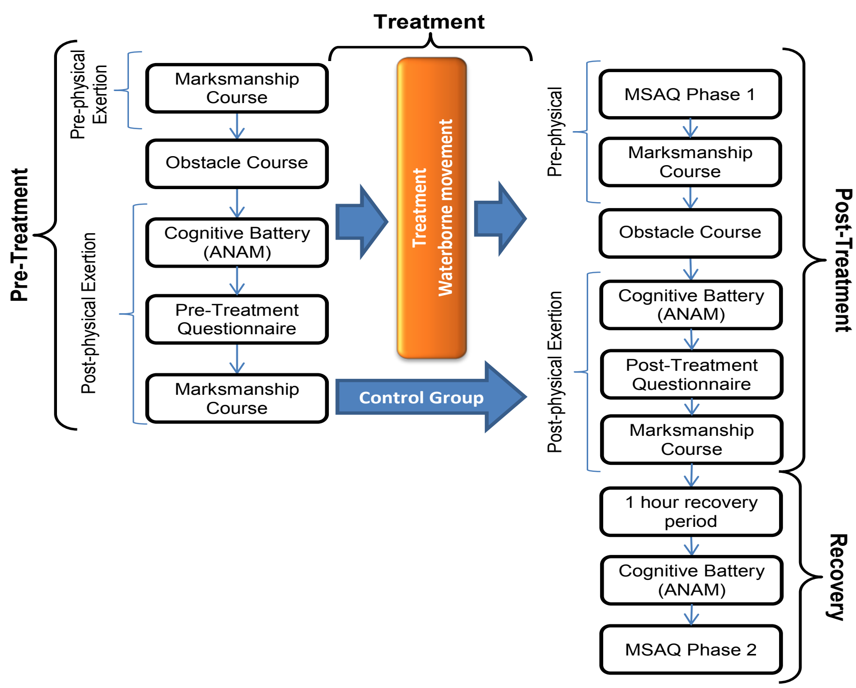

Figure 1. HAT study design for performance tests each day. (Taken from AVTB, 2011, 2012).

RESULTS

Cognitive throughput (i.e., the number of correct responses per minute) as measured by the ANAM Switching Task declined significantly following waterborne exposure. Compared to two hours in a stationary vehicle, two hours of waterborne motion exposure led to a 5.2% reduction in cognitive performance. Three hours of waterborne motion exposure produced a 9.3% reduction ($n = 211$, $F(3,147) = 7.58$, $p < 0.0001$). In other words, those Marines in the water for three hours experienced, on average, an additional one out of ten incorrect decisions.

Figure 2 shows Tukey HSD results of the 6 *post hoc* comparisons of levels of cognitive throughput across the four experimental conditions. Immediately following exposure, the stationary condition was not different from the one-hour condition. However, the stationary condition was significantly different from the two and three-hour conditions and one-hour was different from the two- and three-hour conditions. There was no difference between the two and three-hour exposure conditions.

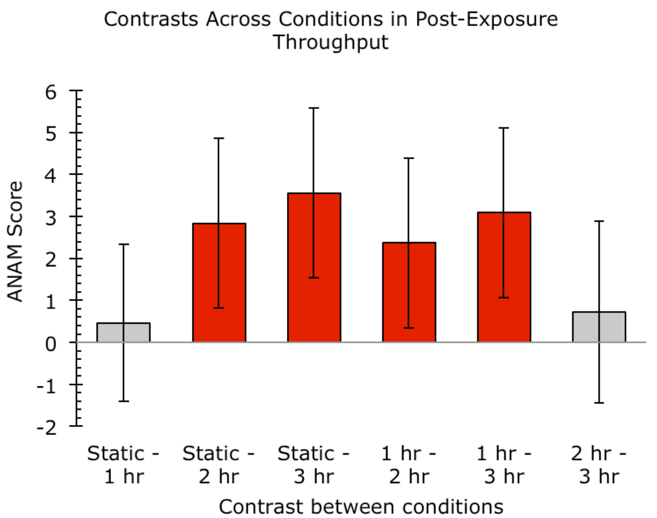

Figure 2. Cognitive throughput following exposure to waterborne motion.

Following an hour allocated for recovery, there were still significant differences in cognitive throughput across conditions (n = 211, F (3,147) = 5.41, p < 0.01). Figure 3 shows the results of the Tukey HSD Test indicating that following one hour of recovery, there were still differences between the stationary and all three (one, two and three-hour) of the other conditions but there were no differences among any of the other conditions. In other words, after one hour allowed for recovery, cognitive throughput was still reduced at all three motion exposure conditions as compared to the stationary condition.

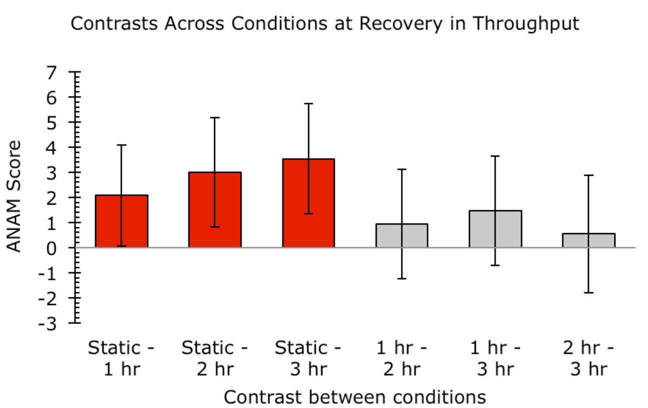

Figure 3. Cognitive Throughput (Errors per Minute) as measured by AMAM Switching Task after one-hour recovery following exposure to waterborne motion.

There were statistically significant differences in reaction times for the four conditions immediately after exposure (n = 211, F (3,147) = 3.28, p < 0.023). Multiple comparisons using the Tukey HSD Test shown in Figure 4 indicate that while there were no differences between the stationary and one hour conditions, there were significant differences between the stationary and two and three-hour conditions. There were no differences between any of the other conditions.

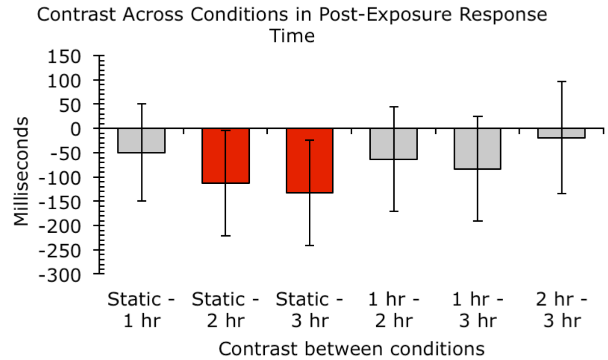

Figure 4. Response times following exposure to waterborne motion.

Self-reported motion sickness was collected using the Motion Sickness Assessment Questionnaire (MSAQ) immediately after exposure and again following a one-hour period of recovery. There was a statistically significant increase in motion sickness noted after 2 and 3 hours of motion exposure when compared to the stationary and one-hour conditions (n = 210, F (3,146) = 10.94, p < 0.0001). Multiple comparisons using the Tukey HSD Test shown in Figure 5 indicate that while the stationary condition was not different from the one-hour condition, the two and three-hour conditions were different from both the stationary and one-hour conditions. The two and three-hour conditions did not differ from each other.

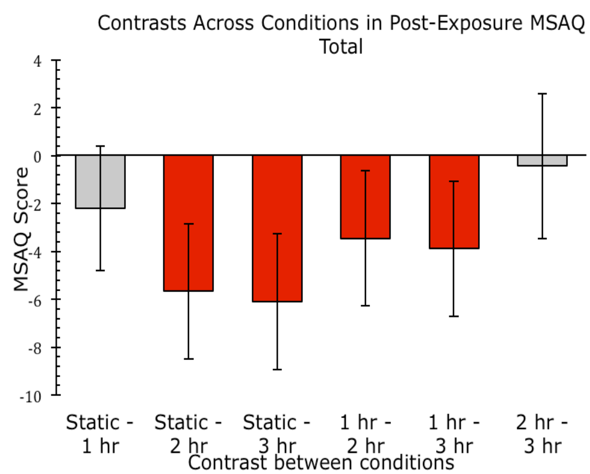

Figure 5. Post-exposure MSAQ Total score following exposure to waterborne motion.

MSAQ scores of Marines exposed to three hours of motion were still significantly elevated after one hour of recovery (n = 209, F (3,145) = 4.71, p < 0.0036). Multiple comparisons using the Tukey HSD Test shown in Figure 6 indicate that the stationary and one-hour conditions were still different from the three-hour condition although none of the other conditions differed from each other. This finding indicates that motion sickness levels subsided during the recovery but did not return to the level found for the stationary condition.

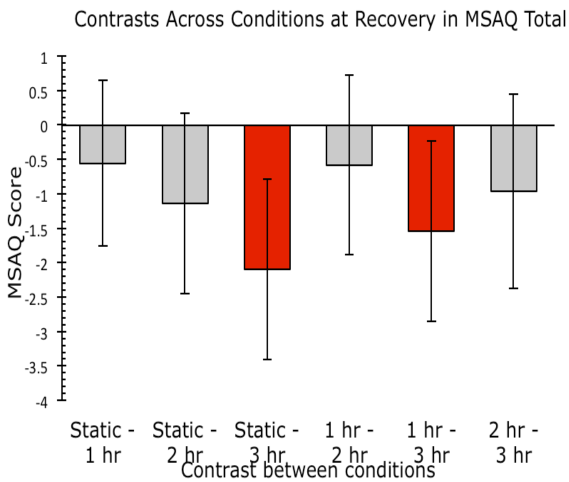

Figure 6. MSAQ Total score after one-hour recovery following exposure to waterborne motion.

DISCUSSION

Our analysis did not identify any performance reduction in marksmanship or obstacle course performance across one, two, and three-hour exposure levels. However, we found significant differences in cognitive throughput (i.e., the number of correct responses per minute) as measured by the ANAM Switching Task. After one hour of recovery, cognitive throughput was still reduced for all three motion exposure conditions as compared to the stationary condition. Furthermore, participants demonstrated increased reaction times in the two and three-hour conditions immediately after exposure compared to the stationary condition.

There was a marked increase in the severity of motion sickness immediately after the two- and three-hour motion exposure conditions when compared to the stationary and one-hour conditions. Even after a one-hour period of recovery, participants in the three-hour motion condition had yet to recover fully.

Limitations of the study include the need for queuing in the marksmanship and obstacle courses. As a result, some Marines took the cognitive battery and the MSAQ before others. It is possible that this introduced uncontrolled variability in the post-treatment and recovery ANAM and MSAQ scores.

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