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USE OF INCREMENTAL ADAPTATION AND HABITUATION REGIMENS FOR  
MITIGATING OPTOKINETIC SIDE-EFFECTS

by

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A dissertation submitted in partial fulfillment of the requirements  
for the degree of Doctor of Philosophy  
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## ABSTRACT

The use of incremental and repeated exposures regimens have been put forth as effective means to mitigate visually induced motion sickness based on the Dual Process Theory (DPT) (Groves & Thompson, 1970) of neural plasticity. In essence, DPT suggests that by incrementing stimulus intensity the depression opponent process should be allowed to exert greater control over the net outcome than the sensitization opponent process, thereby minimizing side-effects. This conceptual model was tested by empirically validating the effectiveness of adaptation, incremental adaptation, habituation, and incremental habituation regimens to mitigate side-effects arising from exposure to an optokinetic drum. Forty college students from the University of Central Florida participated in the experiment and were randomly assigned to a regimen. Efforts were taken to balance distribution of participants in the treatments for gender and motion sickness susceptibility.

Results indicated that overall, the application of an incremental regimen is effective in reducing side-effects (e.g. malaise, dropout rates, postural instabilities, etc.) when compared to a non-incremented regimen, whether it be a one-time or repeated exposure. Furthermore, the application of the Motion History Questionnaire (MHQ) (Graybiel & Kennedy, 1965) for identifying high and low motion sickness susceptible individuals proved effective. Finally, gender differences in motion sickness were not



found in this experiment as a result of balancing susceptibility with the gender subject variable.

Findings from this study can be used to aid effective design of virtual environment (VE) usage regimens in an effort to manage cybersickness. Through pre-exposure identification of susceptible individuals via the MHQ, exposure protocols can be devised that may extend limits on exposure durations, mitigate side-effects, reduce dropout rates, and possibly increase training effectiveness. This document contains a fledgling set of guidelines for VE usage that append those under development by Stanney, Kennedy, & Kingdon (In press) and other previously established guidelines for simulator use (Kennedy et al., 1987). It is believed that through proper allocation of effective VE usage regimens cybersickness can be managed, if susceptible individuals are identified prior to exposure.



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## INTRODUCTION

### Application of Behavioral Modification Regimens for Mitigating Motion Sickness in Various Sensory Environments

Despite the lack of a proven predictive theory of motion sickness and an inability to identify the exact neural pathways involved in motion sickness, enough information is known through empirical investigation of motion sickness' behavioral aspects to be able to apply behavioral modification paradigms (e.g. usage protocols) to overcome the side-effects associated with cybersickness. Cybersickness is a form of motion sickness that occurs as a result of exposure to virtual environments (VE) and is comprised of motion sickness-like symptoms that may occur during usage and continue afterwards (negative aftereffects). It has been reported that 80% to 95% of individuals exposed to a head mounted display VE system report some level of cybersickness, with 5% to 30% experiencing symptoms severe enough to end participation (Stanney, Salvendy, et al., 1998; Wilson, 1997; Howarth and Finch, 1999; Stanney, Kennedy, Drexler, & Harm, 1999). The extent and severity of cybersickness may hinder the advancement of VE technology and, thus, it needs to be curtailed. The sensory conflict theory of motion sickness, the most widely accepted theory, suggests that the intensity of motion sickness is based on the magnitude of a discrepancy signal. The main tenet of the sensory conflict theory is that all situations which induce motion sickness have a condition of sensory

rearrangement where input from the eyes, vestibular system, and nonvestibular proprioceptors are at variance with one another, and with what is expected based on past experience (Reason, 1978, 1969, 1970; Reason & Brand, 1975). It is the variance with what is expected that Reason & Brand (1975) define as the crucial factor for inducing motion sickness. The behavioral aspects of motion sickness may be malleable by applying regimens that yield depression or facilitation of the discrepant signal.

Different regimens (e.g. courses of treatment such as adaptation, cognitive strategies, habituation, dual adaptation, and incremental adaptation/habituation) have been used in various sensory environments with differing degrees of success. These regimens have demonstrated a capability to manipulate the sensory discrepancy and assist in acclimation to novel sensory environments. The various sensory environments these strategies have been employed in include underwater, slow rotation room, simulators, artificial optical distortions, optokinetic drums, combat and aerobatics aviation, zero gravity, and, in some cases, virtual environments. In the following section, these regimens are discussed in regard to their ability to mitigate side-effects, not aftereffects. It is put forth that any regimen that facilitates complete adaptation, except for complete dual adaptation (ability to transition seamlessly between sensory environments), may result in negative aftereffects positively correlated with the extent of adaptation completed. For VE usage regimens that do not have the luxury of implementing a dual adaptation regimen, negative aftereffects may have to be a concession to minimizing side-effects during exposure.



### Regimen: Adaptation

Adaptation (i.e. a decrease in sensory conflict within one prolonged exposure) has been used as an approach for acclimating to the discordances of all the aforementioned sensory environments. Its main requirement is a constant and consistent stimulus, with the amount of adaptation dependent upon stimulus intensity, exposure duration, interaction with the environment, and the individual's neural plasticity. Underwater sensory environment adaptation studies have shown that humans are capable, to varying degrees, of adapting to the visual distortions of an underwater realm based on level of interaction (e.g. swimming vs. performing tasks or playing games) and duration of exposure (Ross, 1970; Luria & Kinney, 1970; Ross, Franklin, Weltman, & Lennie, 1970). Luria and Kinney (1970) found that participants involved in playing underwater games did significantly better than those passively interacting with the environment, achieving levels of adaptation between 60%-100% compared to passive individuals in other studies achieving 20%-25% of possible compensation (Ross, 1970; Luria & Kinney, 1970).

Adaptation studies in the Pensacola Slow Rotation Room (SRR) have been performed to investigate acclimation to its provocative characteristics over extended periods of time. Graybiel et al. (1965) looked at the effects of exposing four naval aviators for twelve days to the SRR rotating at a speed of 10rpm. The investigators found that nausea symptoms decreased over time, while fatigue and drowsiness persisted. Upon cessation, only one participant exhibited mild nausea and ataxia was short lived, suggesting that complete adaptation had not occurred, potentially due to the high intensity of the stimulus. Ataxia is a marker of adaptation because for an individual to walk in a straight line relative to the SRR, the individual must actually move in a curved



path to the earth. Therefore, upon cessation and egress, if the individual exhibits ataxia (in this case postural instability and locomotion in a curved path when asked to walk straight ahead) we know that the individual has adapted to the novel semi-circular canal stimulation created by the velocity of the SRR (the semi-circular canals provide six degrees of freedom of angular velocity detection). As a result, the investigators suggested employing an incremental adaptation approach to achieve maximal adaptation.

Adaptation has also been shown to occur in zero gravity environments through the presence of ataxia upon returning to a 1g environment (Paloski et al., 1998; Homick & Reschke, 1977; Paloski et al., 1993). In this case ataxia results from having to recalibrate the otoliths to a 1g environment.

Humans have demonstrated the capability to adapt to artificial optical distortions caused by prisms and mirrors. The types of distortions include optical tilt (Ebenholtz, 1969), curvature (Hay & Pick, 1966), inversion (Stratton, 1897), right-left reversal (Kohler, 1964), and distortions in distance (Held & Schlank, 1959) and visual size (Rock, 1965). The literature concerning adaptation in simulators and VEs, in addition to SRR studies, has brought to light the motion sickness aspects of adaptation, particularly visually induced motion sickness. Work by Kennedy et al. (1987) and Stanney et al. (1999) has shown that simulator sickness incidence rates vary from 12% to 70% based on the type of simulator (fixed based vs. motion base, fixed wing vs. helicopter, etc.) and maneuvers being performed.

The side-effects and negative aftereffects associated with adaptation to VEs have also been demonstrated in the literature (Stanney & Salvendy et al., 1998), but the focus here is on side-effects. The high rates of cybersickness and dropouts reported earlier



(Stanney, Salvendy, et al., 1998; Wilson, 1997; Howarth and Finch, 1999; Stanney, Kennedy, Drexler, & Harm, 1999) occurred during studies that employed adaptation regimens. Kennedy, Stanney, & Dunlap (2000) performed a meta-analysis and found that exposure duration is positively related to total sickness, thus increasing sickness as the adaptation process proceeds. Interestingly though, Cobb et al. (1999) reported results of a study where two out of four participants interacting with a VE for up to two hours were able to complete the adaptation process. Peak sickness plateaued at 60 minutes, where two participants (50%) dropped out, to 75 minutes where symptoms began to decrease. At the end of the two-hour exposure, the remaining two participants reported sickness levels equivalent to pre-exposure. However, it should be noted that the two individuals that completed the exposure duration might have been unique in that they were capable of rapidly adapting or they were resistant to visually induced motion sickness.

To sum up the adaptation findings, it is apparent that individuals are capable of adapting to a sensory discrepancy to varying degrees based on time, stimulus intensity, and level of interaction with the novel environment. However, as a price for adaptation there is potential for experiencing side-effects and negative aftereffects. In regards to VEs, it has been shown that these side-effects are strong enough and widespread enough that individuals may not be able to withstand an adaptation regimen, and those that do, may be subject to potentially harmful negative aftereffects such as ataxia and impaired motor control. The implications for the current study are that an adaptation regimen may be too intense for moderate to high motion sickness susceptible individuals, resulting in intense malaise, high dropout rates, and postural disturbances. It is therefore suggested that alternative means to achieving an adapted state be investigated.



### Regimen: Cognitive

One alternative means to facilitating consummation of the adapted end-state has been cognitive interventions, approaches that utilize education about the stimulus effects to be experienced, various forms of performance feedback, and mental exercises (e.g. mental rotation). They have been applied in underwater sensory environments with lackluster success. Luria and Kinney (1970) provided a group of participants an explanation of the distortions they would encounter underwater and then allowed brief practice of the task underwater before testing. Results demonstrated that the cognitive intervention group did significantly poorer than a group allowed to play games underwater for the entire pre-test period (15 minutes). The implication being that stimulus exposure may be more effective than education for maximizing acclimation, at least in an underwater environment.

Parker and Harm (1992) provide anecdotal evidence that mental rotation is key to mitigating motion sickness during space flight. This anecdotal evidence from astronauts states that part of their adeptness to adapt to the 0g environment is their ability to mentally rotate and shift between earth-referenced down and space shuttle cabin-referenced down. One veteran astronaut claimed to be able to mentally rotate any room while on earth and attributed part of the rapidity of his adaptation to this capability.

Experiments on cognitive interventions have also been done on artificial optical distortions (e.g. reversing prisms). In regards to prismatic displacement, it has been shown that providing solely verbal feedback regarding the participant's error in movement is enough to elicit adaptation (Uhlarik, 1973). Dewar (1970) demonstrated



prismatic adaptation from solely verbal feedback to be equivalent to visual and visual - verbal feedback as measured by negative aftereffects.

Cognitive methods have also been employed in VIMS research with some success. Dobie et al. (1987) divided 16 participants into four groups. Group 1 received 10 sessions of confidence building and desensitization training (i.e. education about potential side-effects). Group 2 received 10 sessions of EMG and temperature feedback. Group 3 received 10 sessions of group 1's training and 10 sessions of group 2's training. Group 4 received no treatment and served as a control. The results indicated that groups 1 and 3 exhibited significant increases in tolerance to VIMS in an optokinetic drum when comparing pre and post measures, while groups 2 and 4 did not. The implication of this study is that building an individual's confidence to withstand the symptoms of motion sickness may result in one's ability to delay the maximal onset of ill symptoms. However, this is not substantiated outside of this study and other cognitive therapies, such as education, have not proven effective (Dobie & May, 1990).

Dobie and May (1990) examined the effects of educating the individual as to the process and effects of motion sickness. Participants were then trained on either a rotary chair (rotating and tilt stimulation), optokinetic drum (visually induced apparent motion), or received only cognitive training. They found that the cognitive training alone did not lead to increased tolerance (delay of nausea onset), but it did lead to a decrease in subjective estimates of motion sickness. It is plausible that the cognitive therapy may have over-sensitized the individuals through increased expectation of sickness to occur.

The use of simulators for mental rotation training in an effort to reduce space sickness has been undertaken by Parker and Harm (1992). They utilized the DOME-PAT



(Device for Orientation and Motion Environments Preflight Adaptation Trainer) to hone shuttle astronauts' mental rotation skills by having them move through a simulation of Spacelab while viewing the ceilings as the floors. Anecdotal evidence from astronauts suggests that this cognitive training in the simulator has proven beneficial in being able to mentally rotate the environment when in space, and subsequently, to decrease subjective space sickness while speeding up adaptation.

The cognitive aspects of simulator sickness among crews have also been examined. Findings show that the probability of both individuals in a crew leaving when one was sick was higher than chance (Bitner, 1976). Kennedy et al. (1987) suggest that simulator sickness may be "contagious" through suggestibility. If VEs are to be utilized by multiple participants in close proximity then precautions may need to be considered to contain the potentially "contagious" aspects of cybersickness.

There are few if any studies investigating cognitive training for abatement of side-effects in virtual environments. However, Parker and Harm's (1992) findings suggest that the ability to mentally rotate the environment may be important for VE adaptation, especially when transitioning between real and virtual environments. From the research on cognitive therapies and VIMS in optokinetic drums there may be some merit to incorporating a cognitive component into VE usage protocols to quicken adaptation and reduce subjective cybersickness. Dobie and May (1990) provided potential evidence for the benefits of combining regimens when they found increased tolerance to rotation in a chair and generalization to an optokinetic drum when cognitive therapy was used in conjunction with training in a rotating chair.



The research into cognitive regimens has several implications on this study. First and foremost, the dearth of supporting evidence suggests that cognitive approaches may not be effectual on their own, particularly for motion sickness-inducing stimuli. Second, cognitive approaches require large amounts of interaction with a moderator, which may not be feasible in a real-world setting (e.g. training) where time and resources are scarce. Furthermore, interacting with a moderator may hinder training effectiveness, particularly in training tasks that require solitude and intense concentration. Finally, the results of priming individuals to think about their level of side-effects during exposure is unclear. Therefore, a cognitive approach to mitigating malaise is not being pursued herein.

#### Regimen: Habituation

Habituation, repeated exposures to a stimulus in an effort to decrement response, is another means to achieving an acclimated end state. Investigators using the SRR have utilized habituation regimens and found that there was retention of adaptation with a 7-day intersession interval (ISI), but not with a 30-day ISI (Kennedy, Tolhurst, & Graybiel, 1965). Lackner and Graybiel (1982) reported finding habituation to parabolic flight using a regimen of a 40-parabola flight per day for 4 days. Each day the participants reported a decrease in perceived intensity of force by approximately the 5<sup>th</sup> parabola and a decrease of roughly 40% by the 40<sup>th</sup> parabola. Participants also noted a reduction in perceived intensity of the parabola's force day to day.

In regard to artificial optical distortions, Stern et al. (1989) looked at different ISI for habituation to an optokinetic drum. They found that over 3 exposures to an optokinetic drum, with an ISI ranging from 4 to 24 days, they were unable to achieve



habituation based on subjective report of motion sickness and the presence of tachygastria (a shift in the normal rhythm of the stomach from 3cpm to 4-9cpm). However, participants with an ISI of 2 days showed reduced subjective sickness and diminished tachygastria. Simulators have also demonstrated the value of a habituation regimen where 4 to 6 repeated exposures have resulted in a noticeable decrease in sickness (Biocca, 1992; Regan, 1995). Optimal ISI for simulators has been investigated and results suggest that an ISI of 2 to 5 days is best (Kennedy et al., 1987; Watson, 1998), while an ISI of 1 day or greater than 6 days results in little increased tolerance to simulator sickness (Kennedy et al., 1987).

Habituation has been successfully applied to VEs as well. For example, Kennedy et al. (1996) found marked reductions in side-effects in the second of two 40-minute VE exposures; unfortunately the ISI was unspecified. Cobb et al. (1999) found habituation, particularly in the disorientation subscale of the simulator sickness questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993), over three exposures to a 20-minute passive VE with a 7-day ISI (see Kennedy, Lane, Berbaum, & Lilienthal, 1993 for a detailed explanation of the symptoms associated with the disorientation subscale of the SSQ). Finally, a meta-analysis performed by Kennedy, Stanney, & Dunlap (2000) has shown that repetition (e.g. repeated exposures) is negatively related to total cybersickness.

The habituation literature has various implications on this study. First, the effectiveness of a habituation regimen for mitigating motion sickness has warranted its application herein. From the application of habituation to these various sensory environments it is apparent that a repeated exposure approach has potential value. It



appears that an ISI between 2 and 5 days, potentially up to 7 days, is optimal for achieving habituation, and the critical number of exposures has been shown to vary between 2 and 4 sessions. However, the habituation approach does not address side-effects associated with the initial exposure before habituation has occurred. It is therefore suggested that repeated exposures are beneficial, but stimulus intensity and duration of exposure during initial sessions may need to be manipulated to achieve optimal acclimation.

#### Regimen: Dual Adaptation

An extension of the habituation paradigm is dual adaptation. Dual adaptation is the capability to adapt to two or more conflicting sensory environments. It results from frequent alternations between one (or more) rearranged sensory environments and the normal sensory environment, which leads to decreased negative aftereffects at the point of changeover between the two sensory environments and/or more rapid reacquisition of the environment appropriate perceptions and behavior (Welch et al., 1993). The dual adapted state does not mean the individual remains adapted to other sensory environments during periods in a particular sensory environment, but instead possesses a readiness to adapt or readapt. This has been discussed as a plausible explanation for the ability of experienced SCUBA divers to adapt significantly faster than novice divers to the distortions of the underwater environment (Ross, 1970; Ross et al., 1970). Dual adaptation has also surfaced unintentionally in the SRR literature as a result of experimenters working shifts during prolonged studies. Graybiel, Deane, & Colheur (1969) and Graybiel et al. (1965) have noted the presence of dual adaptation in their on-



board experimenters' diaries. The on-board experimenters indicated that at the beginning of the studies they experienced the same malaise and fatigue as the participants upon ingress and egress from the SRR. However, by the end of the studies these experimenters wrote that they were capable of ingress and egress with minimal or non-existent malaise and ataxia.

Dual adaptation has also been found in a study on parabolic flight where participants reported feeling abnormally light upon return to a 1g environment for only a minute or two by the end of 4 days of 40-parabola flight (Lackner & Graybiel, 1982). Dual adaptation was also put forth as a possible explanation for the finding of significantly less postural sway in veteran astronauts in comparison to rookies on certain postural stability tests (Paloski et al. 1999). Empirical investigation of dual adaptation has been carried out using artificial optical distortions and has shown that humans are capable of achieving a dual adapted state for prismatic displacement and VOR gain (Welch et al., 1993; Shelhamer, Robinson, & Tan, 1992; Welch et al., 1998; Post & Welch, 1998).

Little, if any, empirical research explores dual adaptation in simulators or virtual environments. However, Welch (In Press) suggests that systematically alternating VE users between one or more VEs and the normal sensory environment could yield dual adaptation and, subsequently, an ability to interact with a given VE with negligible side-effects and minimal negative aftereffects upon returning to the normal sensory environment. He posits that the ideal dual adaptation regimen would include an unlearning/relearning approach where the VE user performs the VE task, or one very similar, in the normal sensory environment. This task should require the individual to perform the same visual-motor actions that were performed in the VE, thus accelerating



readaptation. From the literature it appears that dual adaptation may be a panacea for overcoming cybersickness and the associated negative aftereffects, but it, too, has demerits. As with habituation, the problems of side-effects and negative aftereffects in initial sessions are not addressed. In addition, this approach requires adaptation to the altered sensory environment at some point, which may not be achievable for some individuals if the current high cybersickness dropout rates and 15-minute exposure limit recommendations (Knerr et al., 1998) are accurate. Finally this approach requires maintenance of the dual adapted state, and if extrapolations can be made from maintenance of adaptation data gathered from the habituation studies in SRRs and simulators, the frequency of exposure may have to be weekly.

Due to the high number of exposures required to achieve dual adaptation and the strict adherence to an optimal exposure schedule, a dual adaptation protocol is not being investigated herein. In addition, the requirement of a validated readaptation battery further precludes its use in this experiment. However, this should not downplay its potential value as a superlative approach for mitigating side-effects in individuals that frequently interact with a multitude of provocative environments, as long as time is available for properly undertaking the regimen.

#### Regimen: Incremental Adaptation

Incremental adaptation is another approach to promoting adaptation to altered sensory environments. This approach facilitates achieving an adapted end state to a goal stimulus intensity by adapting to stepwise increments in intensity over time, whether it is within one session or across multiple sessions. An incremental adaptation approach has proven its worth in preventing motion sickness in the Pensacola SRR. Graybiel, Deane, &



Colehour (1969) demonstrated prevention of overt motion sickness symptoms in four 17- to 19-year-old Navy enlisted men using nine stepwise increments over a period of 16 days to reach a terminal velocity of 10rpm. The protocol called for counterclockwise rotation beginning at 2rpm and increasing the velocity by 1 rpm every other day until 10rpm was reached, at which point it was kept at 10rpm for the remaining days. Cramer, Graybiel, & Oosterveld (1978) demonstrated the successful transfer of incremental adaptation in the SRR to the Navy flight training environment on two participants that were on leave from flight training due to repetitive occurrence of acute airsickness. This regimen also entailed 1rpm increments in the protocol and lasted up to 10days. Reason and Graybiel (1970) performed a study using the SRR to determine the ideal stepwise increment for adaptation to Coriolis forces associated with head movements in the SRR. They wanted to know if the size of the increment was the same for each stepwise increase or if it varied as a function of absolute stimulus intensity (e.g. does a 1-2rpm step require the same increment as a 9-10rpm step?). Six out of ten participants completed the study upon which the investigators deduced that the size of the increment (in this case the total number of head movements required to achieve adaptation to a particular velocity) increases as a power function of the stimulus strength (in this case velocity). They also noted that there were large individual differences in the rate of adaptation.

The Royal Air Force has also applied incremental adaptation in motion sickness desensitization programs. Bagshaw and Stott (1985) discuss the effectiveness of incremental adaptation in both the ground phase of desensitization (similar to the Pensacola SRR head movement protocols, but instead using a rotating chair) and in the flight phase. They report success in desensitizing airsick crewmembers and attribute it to



1rpm steps in the ground phase and to a slow progression from straight and level flight to advanced aerobatics and high-speed, low level flying in the flight phase. Empirical support for the utility of an incremental approach also stems from the research on artificial optical distortions where it was shown that a stepwise approach can achieve adaptation to optical tilt (Ebenholtz & Mayer, 1968) and increases the rate of adaptation in comparison to a non-stepwise approach (Lackner & Lobovitz, 1978; Hu, Stern, & Koch, 1991).

Watson (1998) used a form of incremental adaptation in which she briefly (5 minutes) exposed participants to an extremely high intensity driving simulation and then tested the participants on a lower intensity driving simulation on a second visit 1, 2, 3, or 18 days later. She found that upon the second visit, SSQ total scores dropped as well as the disorientation and nausea subscales. Unfortunately, her findings do not state if the SSQ total and subscale scores on the second visit were significantly higher than baseline scores before the 5-minute high intensity exposure. Kennedy et al. (1978) also proposed that simulator sickness can be mitigated by using an incremental adaptation approach, specifically, gradually increasing exposure duration and intensity of flight maneuvers (i.e. from less acrobatic to more intense). They suggest an initial gradual increase in simulator flight maneuvers to keep lag and forms ofvection (particularly yaw) to a minimum.

Few, if any, applications of an incremental regimen can be found in the cybersickness literature, but its merits are lauded as part of an ideal adaptation regimen for VEs by Welch (In Press). Similar to Kennedy et al. (1987) Welch suggests gradually increasing exposure duration and magnitude of the sensory discrepancies as part of the regimen. Based on the literature it can be suggested that an incremental approach to



combating cybersickness may be optimal for single-use users as this approach may afford a faster rate of adaptation than standard adaptation protocol (i.e. one prolonged exposure at full stimulus intensity), while keeping side-effects to a minimum. However, it should be noted that individual user differences and characteristics of the VE itself (e.g. degrees of freedom of motion, textures, lag) will likely mean that unique incremental protocols will be needed for VEs that produce different levels and types of cybersick-provoking stimuli. In addition, an incremental approach may increase the intensity and duration of negative aftereffects if this regimen leads to more complete adaptation as suggested by the SRR literature. Despite this, an incremental approach may be a means to extending exposure durations that could increase the utility and return on investment of VE systems deployed for training. It could also be beneficial for single-use or infrequent users, while frequent users may benefit from incremental adaptation along the path to achieving dual adaptation (possibly the optimal situation).

The body of research on incremental regimens has a variety of implications on this study. First, selecting the proper increments in stimulus intensity is essential for maximizing the rate and extent of acclimation. In addition, determining acclimation criteria or minimum exposure durations for each increment in stimulus intensity is also paramount. The potential for negative aftereffects is greater with an incremental approach because of the likelihood of achieving greater amounts of adaptation. Finally, an incremental approach is likely best suited for individuals of moderate to high motion sickness susceptibility that cannot withstand an adaptation regimen.

Table 1 provides a graphical depiction of which regimens have been employed in the aforementioned sensory environments; empty cells indicate where empirical findings



in the literature are not present for a particular combination of regimen and sensory environment. This table also provides a rough order of magnitude of each regimen's success and drawbacks in the sensory environments.

Table 1. Matrix of motion sickness reducing regimens application by sensory environment, demonstrating rough order of magnitude success and drawbacks

		Underwater	SRR	0 Gravity/ Flight	Artificial Optical Distortions	Simulators	VEs
<b>Adaptation</b>	<i>Success</i>	L	M-H	H	H	L	L
	<i>Drawbacks</i>	NA	SE, NA	SE, NA	SE, NA	SE, NA	SE, NA
<b>Cognitive</b>	<i>Success</i>	L		M	M-H	M <sup>3</sup>	
	<i>Drawbacks</i>			SE <sup>1</sup> , NA	NA	SE <sup>2</sup>	
<b>Habituation</b>	<i>Success</i>		H	H	H	H	H
	<i>Drawbacks</i>		DSE, NA	DSE, NA	DSE, NA	DSE, NA	DSE, NA
<b>Dual Adaptation</b>	<i>Success</i>	H	H	H	M-H		
	<i>Drawbacks</i>	DNA	DSE, DNA	ISE, DNA	DNA		
<b>Incremental Adaptation / Habituation</b>	<i>Success</i>		H	M-H <sup>4</sup>	H	M-H	
	<i>Drawbacks</i>		SE, DSE, NA	SE, DSE, NA <sup>4</sup>	NA	SE, DSE, NA	

Table 1. L = limited success, M = moderate success, M-H = moderate to high success, H = high success, NA = negative aftereffects, DNA = decreasing negative aftereffects over sessions, SE = side-effects, DSE = decreasing side-effects over sessions. 1 = presence of side-effects and negative aftereffects as the result of the adaptation process which was anecdotally claimed to be facilitated by mental rotation skills. 2 = side-effects resulting from the "contagiousness" of simulator sickness among crew members. 3 = anecdotal evidence suggests mental rotation aids adaptation. 4 = in regards to airsickness desensitization training. Empty cells indicate where empirical research has not been performed. SSR = Slow Rotation Room; VE = Virtual Environment.

The general implications of Table 1 are that cognitive regimens have been relatively ineffective in mitigating motion sickness and aiding acclimation to various stimuli. Adaptation protocols have been more effective in promoting acclimation to non-



motion sickness inducing stimuli, but are less capable for reducing malaise in susceptible individuals. Habituation and dual adaptation regimens are a promising approach for acclimating to a variety of stimuli, including those that induce motion sickness. However, they require time and adherence to a narrow range of exposure intervals. Finally, incremental protocols are a versatile approach that can be applied with success to a wide array of stimuli, including motion sickness stimuli, in either a single or across repeated exposures. In regard to selecting regimens for acclimating to motion sickness-inducing stimuli, it is suggested that an incremental approach be utilized for single exposures. For repeated exposures it is suggested that an incremental approach be utilized for more intense stimuli and that a dual adaptation regimen be employed when an individual is required to seamlessly transition between two or more sensory environments.

#### Selecting a Regimen for One Prolonged Exposure or Multiple Infrequent Sessions

From the summaries provided above it is suggested that the intended duration and number of VE exposure sessions will determine the type of VE adaptation regimen that should be employed. For instance, a training program that utilizes a VE repeatedly (i.e. every other day) over a month-long session may consider employing a dual adaptation regimen that incorporates incremental adaptation both within and across exposures. The focus here is on increasing tolerance beyond the current 15-minute exposure recommendations (Knerr et al., 1998) for training programs that entail one prolonged single VE session, or multiple infrequent sessions.

It has been shown that pure adaptation (i.e. one prolonged exposure to the full intensity of a VE's sickness provoking stimuli) may lead to a complete cycling of



subjectively reported side-effects (i.e. progression from no, or negligent, symptoms pre-exposure, to maximal side-effects and returning to a level not significantly different from pre-exposure levels while interacting with the VE) if the participant can withstand the cybersickness (Cobb et al., 1999). However, the number of individuals who are capable and willing to withstand intense side-effects may be limited. In addition, performance within the VE may be impaired by sickness to the point where negative transfer of training occurs (due to acquisition of inappropriate behaviors, such as limiting head movements to reduce adverse effects). Interestingly, Lanham (2000) reports that despite an increase in sickness over exposure duration, participants were able to maintain performance in tasks associated with the Virtual Environment Performance Assessment Battery (Lampton, Knerr, Goldberg, Bliss, Moshell, & Blau, 1994). These findings suggest that participants, despite sickness, might be able to maintain performance during prolonged sessions. However, it remains to be seen if users would be willing to use a VE system that repeatedly induces intense cybersickness.

The idea of applying an incremental adaptation or incremental habituation approach, as compared to a single long-duration exposure at full intensity, is put forth as a means to minimizing side-effects, increasing tolerance, and subsequently prolonging exposure time and potentially maintaining human performance levels in a VE.

#### Justifying Application of an Incremental Regimen Using the DPT of Neural Plasticity

The Dual Process Theory (DPT) of neural plasticity (Groves & Thompson, 1970) provides a theoretical means for understanding how particular exposure regimens to various motion sickness inducing environments may affect the magnitude of a sensory



conflict. In summary, the DPT states that there are two opponent processes undertaken upon stimulus onset. The two processes are depression and sensitization, which are carried out in parallel through different tracks. The depression process occurs along the stimulus-response (S-R) pathways while the sensitization process is undertaken through the "state" system (i.e., the Central Nervous System (CNS)). During stimulus processing a confluence occurs where the processes converge to yield the observed response. The observed response is a function of the integration of these two paths and their characteristics based on stimulus strength and number of stimulus exposures. The important aspects of depression and sensitization's characteristics are as follows. Depression is a negative exponential function of the number of stimulus presentations, and its rate and degree are directly proportional to the number of stimulus exposures. Furthermore, the rate and degree of depression are inversely proportional to stimulus intensity; however, intensity is a less significant factor than number of stimulus exposures.

In regard to sensitization, stimulus intensity plays a significant factor in its rate and degree. As stimulus intensity increases, the sensitization opponent process exerts greater influence over the net outcome. If the stimulus is extremely intense, it may result in supramaximal sensitization, thereby dampening sensitization, and the net outcome is not feasible. However, sensitization may depress if stimulus intensity is not extremely high, and repeated, or prolonged, exposures to the sensitizing stimulus are provided. Sensitization may be categorized as either extrinsic or intrinsic (Groves & Thompson, 1970). Extrinsic sensitization involves sensitization resulting from stimulation to a different area (i.e. different part of the body) and/or sensory modality other than that



stimulated by the initial stimulus. Intrinsic sensitization is the result of stimulation to the same area and sensory modality as the initial stimulus. The importance of intrinsic sensitization is that it allows the same stimulus to elicit depression and sensitization in parallel, the basis of this theory.

In essence, the stimulus intensity sets the relationship between the opponent processes, which determines the proclivity of plasticity and the degree to which each opponent processes contributes to the net outcome. Concurrently, number of exposures co-determines the rate of depression, and to a lesser extent, the depression of sensitization. As stimulus intensity increases, the sensitization opponent process plays a more dominant role in determining the net outcome, and the effect of the depression opponent process wanes. The aspect of the DPT of concern here is the sensitization opponent process and how it may be shaped, and, subsequently, the depression curve as well, through behavioral modification (i.e. VE usage regimens). It is herein hypothesized that the sensitization opponent process' effect on net outcome determines the degree of side effects experienced (i.e. net outcome is equivalent to degree of cybersickness). In other words, as stimulus intensity increases the influence of the sensitization opponent process increases, thereby exerting greater control over the net outcome (i.e. subjective motion sickness). This is similar to the idea of long-term potentiation, which is a long-term increase in the excitability of a neuron due to a particular input, particularly if exposure to the input is repeated with a brief interstimulus interval.

The DPT (Dual Process Theory) (Groves & Thompson, 1970) can be used to explain why the implementation of an incremental regimen may be advantageous over the other regimens in regard to minimizing side-effects, increasing tolerance, and



prolonging exposure time in single or infrequent VE exposures. To aid comprehension of DPT application to each regimen, an explanation of the necessary and sufficient components of a DPT model is requisite. Using existing mathematical models (Prescott, 1998; Prescott & Chase, 1999) of the DPT of neural plasticity, it is possible to build an opponent process model. The model presented in Figure 1 is a simplistic version introduced solely to visually depict the hypothesized points of induction and expression of sensitization and depression based on the work of Prescott (1998) and Prescott and Chase (1999).



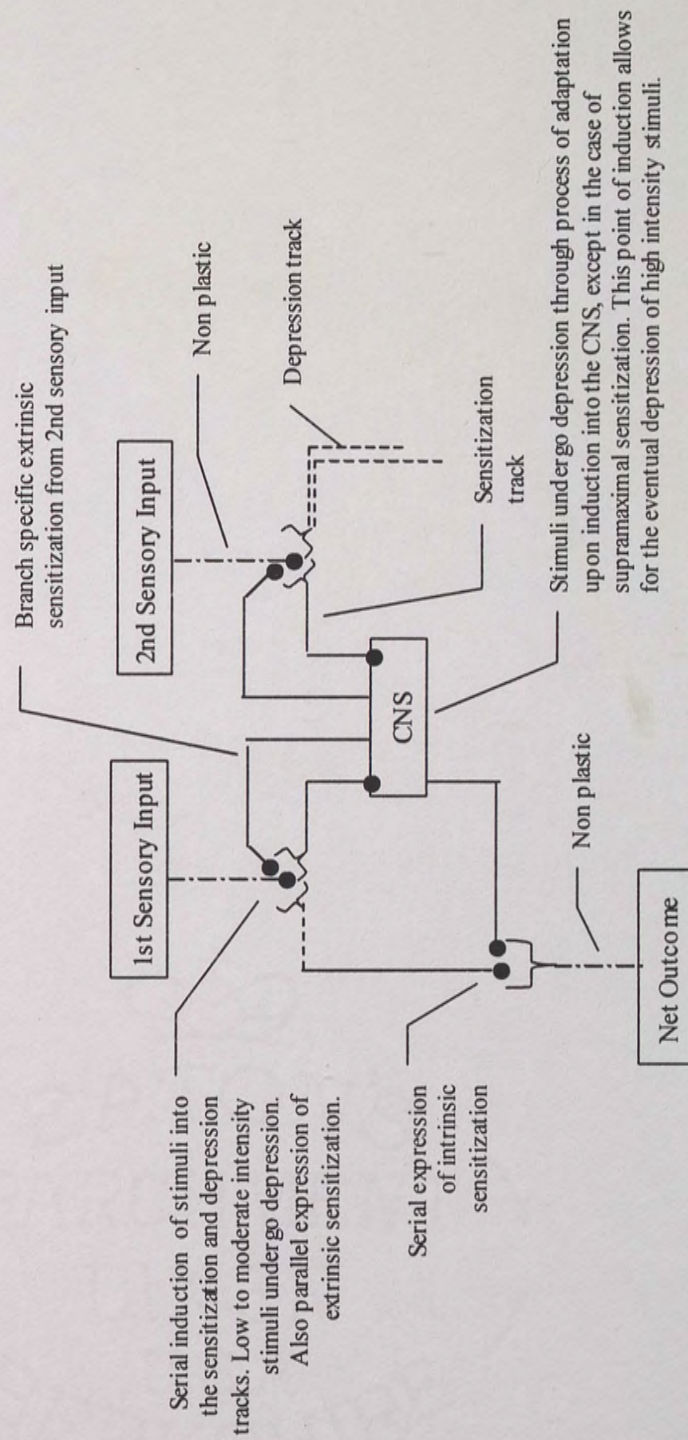


Figure 1. DPT points of induction and expression of sensitization and depression.



The first node in the model represents a locus of serial induction of the stimuli (e.g. sensory conflict in the case of motion sickness) from the primary sensory input (i.e. 1<sup>st</sup> sensory input) into the depression and sensitization tracks. The degree to which each track is “excited” is a function of stimulus intensity, as stimulus intensity increases the sensitization track becomes more “excited.” This locus also represents the point of parallel expression of extrinsic sensitization from contralateral sensory inputs (i.e. 2<sup>nd</sup> sensory input). At this locus, depression may reduce the intensity of the stimulus if it is of low to moderate intensity; otherwise it will proceed at its original intensity as it diverges from this juncture through both the sensitization and depression tracks. The sensitization track is inducted into the CNS (state system) where the stimuli, regardless of intensity, undergoes depression via the process of adaptation. However, supramaximal sensitization is the exception. In this case the stimulus intensity is of sufficient strength to inhibit the adaptive process, yielding a continued state of heightened sensitization that does not depress. The CNS is characterized as being a central locus of induction for all of the sensitization tracks from various inputs (e.g. stimulation from different body parts, an array of sensory conflicts, etc.). This provides the capability for branch specific extrinsic sensitization, in other words excitation via sensitization from other sources of input (i.e. 2<sup>nd</sup> sensory input in figure 1) even if intrinsic sensitization has been depressed. Prescott (1998) posits that the processes of depression and sensitization respectively divide and multiply the strength of the neural signal. Therefore, in order for facilitation via extrinsic sensitization it must be expressed in parallel rather than serially. If sensitization only acted serially (e.g. following depression) then it would be working merely in a restorative manner, because depression would have already divided the signal. Thus, sensitization is



multiplying a continually decreasing value while the multiplier (i.e. sensitization) itself is continually decreasing as a result of the serial induction. A parallel expression, which allows the opponent processes to act on the same synapse individually but simultaneously, yields an output from that synapse that is an additive function of the effects of depression and sensitization instead of a product or quotient, as is the case in a serially induced synapse. It should be noted that parallel expression of extrinsic sensitization at the first plastic locus responsible for depression does not create a positive feedback loop (Prescott, 1998; Prescott & Chase, 1999). In other words, these forms of expression do not beget further sensitization creating a self-sustaining cycle of heightened sensitization. This allows the adaptive process at the point of induction into the CNS to depress sensitization over time, barring supramaximal sensitization. Finally, in the lower portion of the model, the expression of intrinsic sensitization and expression of depression come together at a confluence of induction to yield the net outcome of the two opponent processes.

Taking into consideration the hypothesized loci of induction and expression of sensitization and depression, and that depression and sensitization serve to divide and multiply respectively the stimuli's strength, the DPT can be applied to the regimens of adaptation, habituation, and incremental adaptation for a better understanding of why one might opt for an incremental regimen for one time or infrequent VE exposures.

#### Application of DPT to the Regimens: Adaptation

An adaptation protocol subjects the VE user to the full intensity of the cybersickness provoking elements in the VE for one prolonged exposure. Assuming the



user is not interacting with a benign VE and the intensity of the cybersickness-provoking stimuli can be categorized as “high”, the DPT suggests the following effects. Due to the high intensity of the stimulus there should be minimal depression at the first plastic locus and minimal absolute depression over time as well. Therefore, the stimulus will be inducted into the CNS at near full intensity, resulting in a sensitization dominated net outcome. The DPT predicts that the user will experience a high degree of side-effects that continue for a prolonged period of time as the adaptive process is undertaken in the CNS. However, sensitization will eventually return to pre-exposure levels if the user can withstand the side-effects and supramaximal sensitization does not occur. The rise in the influence of the sensitization opponent process is suggested to be synonymous with the registering of the sensory discrepancy in Welch’s (1978) model of the adaptive process. Welch states that the rate of the adaptive process is positively correlated with the clarity, intensity, and number or registered discrepancies. Thus, the temporary rising in sensitization’s influence may be a reflection of the clarification and intensification of the registered discrepancy(ies). This is also congruent with Reason’s (1978) sensory conflict theory that states that even if a match is found that diminishes the discrepancy between current and expected sensory input, a period of consolidation of the match must still be undertaken, during which side-effects may result. In summary, DPT suggests that application of an adaptation regimen to a high intensity cybersickness-provoking stimulus may result in a high degree of side-effects that persist for a prolonged period of time as sensitization gradually returns to pre-exposure levels via the adaptive process.



### Application of DPT to the Regimens: Habituation

In the case of a habituation regimen (i.e. repeated exposures to a discrepant stimulus) the intensity of the stimulus is not manipulated and, thus, this regimen does not affect the degree to which the sensitization and depression opponent processes exert influence on the net outcome. However, the rate of depression of sensitization to a given stimulus intensity may be faster using a habituation regimen than an adaptation regimen because the DPT suggests that depression is a negative exponential function of the number of stimulus presentations. The idea of opponent process neural plasticity is based on the cellular connection approach to learning that states that learning is merely encoded by changes in specific neurons and their synaptic connections to other neurons. Research shows that previous experience can affect the excitability of sensory neurons, interneurons, and motoneurons (Klein & Kandel, 1978, Kanz et. al., 1979; Frost et al., 1988; and Trudeau & Castelluci, 1993), even if the previous experiences did not cause plasticity (Marcus et al., 1988; Fischer et al., 1997). This capability for memory is thought to occur at the neurons and at their synaptic connections and, then is distributed throughout the network in a manner consistent with parallel processing (Prescott, 1998; Frost et. al., 1988; Lockery & Sejnowski, 1993). According to Welch's (1978) model of the adaptive process and Reason's (1978) sensory conflict theory, as exposure to the stimulus is repeated (in Reason's model prolonged exposure as well) traces of the stimulus are amassed in a neural storage (i.e. memory at the synaptic junctures) where they eventually become the norm for a comparator unit that is attempting to reduce the aversive drive in Welch's model or the mismatch between current and expected sensory input in Reason's model. Welch's model of the adaptive process states that the repeated



exposures will reduce the aversive drive below threshold of detection faster than the concurrent process of adaptation, resulting in incomplete adaptation. Dual process theory provides the capability for this by showing that memory may be occurring at the synaptic junctures and that the traces stored there can be distributed throughout the network (i.e. to the comparator unit) via parallel distributed processing. In theory, Welch's model of the adaptive process suggests that using a habituation regimen should result in a lower magnitude of negative aftereffects in comparison to an adaptation regimen because less adaptation occurs before the aversive drive is abated below threshold of detection. In addition, the repeated transition between altered sensory environment and real world will hasten the recalibration of one's senses, particularly if the individual performs a real world analog of the task performed in the altered sensory environment. This approach also suggests that the time taken to complete the sensitization lifecycle should shorten as a result of an increase in the weighting of neural traces associated with a particular altered sensory environment to which the individual is being repeatedly exposed. Thus, with each subsequent exposure, the traces associated with that particular altered sensory environment are retrieved and consolidated more rapidly.

#### Application of DPT to the Regimens: Incremental Approach

By using an incremental approach, it is assumed the stimulus intensity will be low enough that a significant portion of its intensity would be depressed at the first plastic locus. This would leave a less intense stimulus to be inducted into the CNS and subsequently minimal sensitization. If the VE user is able to complete the adaptive process at each increasing increment of stimulus intensity (i.e. depressing sensitization to



pre-exposure levels or below) within one prolonged exposure, over repeated exposures in one session, or over repeated exposures across multiple sessions, then each stepwise increase in stimulus intensity, assuming the increase is within the bounds of the first plastic locus' depressing capabilities, should keep the magnitude and duration of sensitization to a minimum. In theory, this should afford attainment of exposure to stimulus intensities that would normally result in supramaximal sensitization without experiencing supramaximal sensitization. It is also plausible that the sum of the duration to depress sensitization to baseline levels at each increment may be less than if an adaptation regimen was used to achieve acclimation to a common goal stimulus intensity. Therefore, according to DPT, using an incremental approach should result in both minimal sensitization that dissipates relatively quickly and near maximal depression that will gradually dominate the net behavioral output over time.

#### Candidate Variables for Incremental Manipulation

From the previous sections it is suggested that an incremental regimen may be a better approach to facilitating adaptation and mitigating side-effects than one that exposes the user to the full intensity of the stimulus. Based on this rationale, one must determine how to incrementally manipulate intensity as a means of facilitating acclimation to the stimulus. Utilizing an incremental habituation-based regimen may be more effective for facilitating the acclimation process and mitigating side-effects than an incremental adaptation-based regimen because of the effect of repeated exposures on the depression opponent processes. Dual process theory of neural plasticity states that depression is a negative exponential function of the number of stimulus presentations and that the rate



and degree of depression are directly proportional to the number of stimulus exposures (Groves & Thompson, 1970). Therefore a regimen that uses repeated exposures to a low intensity stimulus (e.g. incremental habituation) should yield a faster and greater depression of side-effects than a one-time incremental exposure (e.g. incremental adaptation). From these suggestions, a 2 by 2 matrix has been formed (see Table 2) as a framework for explaining the selected candidate variables for manipulation. These variables have been selected because of their theoretical relevance and their ability to be manipulated incrementally. To carry-out an investigation of these treatments, a means to empirically manipulate stimulus intensity is needed. Several factors have been cited as affecting stimulus intensity in an optokinetic drum (Hu et al., 1997; Graaf, Wertheim, Bles, & Kremers, 1990; Post, 1988), but the factors selected for this study are velocity and inter-session interval.

Velocity was selected because it has been shown that angular velocity determines circular vection (Graaf, Wertheim, Bles, & Kremers, 1990; Kennedy et al., 1996)) and it can be precisely manipulated. Inter-session interval was selected because it is advantageous in regards to its ease of application. It is a variable that did not require technical expertise to implement (e.g. no requisite programming skills or hardware knowledge) and it is one that could be incorporated into a training curriculum. This variable also allows some flexibility in its application (e.g. between 2 to 7 days) while maintaining its effectiveness for reducing subjective side-effects.



Table 2. Framework for optokinetic stimulus intensity manipulation.

	Adaptation	Habituation
Stable, High Intensity		
Incremental Intensity		

### Adaptation vs. Habituation: Manipulating Intersession Interval

The primary difference between an adaptation and habituation regimen is that an adaptation regimen utilizes one prolonged exposure to facilitate the adaptive process, whereas habituation utilizes repeated exposures. One means of establishing a repeated exposures methodology is to vary the intersession interval (ISI) and, in some cases, the repeated exposures interval within a session (REIWS). It has been shown that trying to complete the adaptive process in one prolonged exposure (e.g. adaptation regimen, ISI or REIWS of 0) can produce side-effects based on the intensity of the stimulus (Wilson, 1997; Howarth & Finch, 1999). However, applying various ISI and REIWS lengths  $>0$  to different altered sensory environments (Pensacola SRR, parabolic flight, optokinetic drums, simulators, VEs) has been shown to have differing degrees of success as summarized in Table 3. The important aspects of Table 3 to extract are that 1) an ISI of 2 to 7 days may be optimal for facilitating the adaptive process across repeated exposures; 2) an REIWS  $<120$  minutes may be detrimental to the individual by increasing their sensitization to provocative stimuli.

However, making blanket statements of recommended ISIs should be done with caution due to variations in individuals' susceptibility to motion sickness. Wilpizeski, Lowry, Miller, Smith, and Goldman (1987) eloquently demonstrated this susceptibility issue while studying the adaptation and habituation of motion-induced vomiting in



squirrel monkeys. Application of a 1 day ISI to squirrel monkeys rotating for one prolonged 8-hour session had different effects based on the monkey's susceptibility to experiencing motion sickness. Those monkeys that were highly susceptible, dubbed "early vomiters" (e.g. initial 8-hour session yielded approximate average of emesis onset latency of 18 minutes; approximate average emesis frequency of 15 times) benefited greatly from the 1-day ISI, showing a positive linear trend in emesis latency (e.g. latency of emesis onset increased) over the 10 successive exposures, resulting in an approximate average latency of 30 minutes. These "early vomiters" also showed a negative exponential trend in vomiting frequency (e.g. frequency of emesis diminished) over the 10 successive exposures, ending in an approximate average of 7 times, with a low point of 5 on day 9. Conversely, monkeys that were moderately susceptible, dubbed "late vomiters" (e.g. initial 8-hour session yielded approximate average of emesis onset latency of 48 minutes, and initial approximate average emetic frequency of 4) did not benefit from the 1-day inter session interval. Data collected between days 1 and 5 showed a negative linear trend in emesis latency (e.g. shorter latency to emesis onset) resulting in an approximate average latency of 20 minutes by day five. Frequency of emesis showed a positive linear trend (e.g. increased frequency of vomiting) over the five days, yielding an approximate average frequency of emesis of 9 times. Days six through ten for the "late vomiters" showed a trend characteristic of habituation, but this habituation effect only returned them to approximate averages near initial values (latency = 47 minutes, frequency = 4) by day ten. It is foreseeable that the habituation effects may have continued if further data collection was performed. The important aspect of the Wilpizeski et al. (1987) study is that different ISIs may have different effects on VE users



based on their predisposition for motion sickness susceptibility. Therefore, ISIs may have to be tailored to groups of individuals based on their susceptibility.

Table 3. Effect of ISI on subjective motion sickness.

ISI or REIWS	Significant reduction of Motion Sickness (MS)?
5 min	No (MS intensity significantly increased over 3 trials separated by 5 min REIWS as compared to pre-exposure. After 15 min REIWS another 3 trials separated by 5 min resulted in an insignificant change in MS as compared to before the 15 min break, however, 25% of Ps had already withdrawn from experiment <sup>9</sup> )
15 min	No (Significant increase in sensitization <sup>1</sup> ; MS intensity maintained <sup>9</sup> ; MS intensity returned to pre-exposure levels during REIWS, but upon return to VE returned to full intensity within 2 minutes <sup>10</sup> )
30 min	No (Significant increase in sensitization <sup>1</sup> )
60 min	No (Insignificant increase in sensitization <sup>1</sup> )
120 min	No (Significant increase in sensitization <sup>1</sup> )
1 day	Yes (over 5 exposures <sup>1</sup> ; in regards to perceived intensity <sup>2</sup> ; immediate post exposure SSQ disorientation subscale score <sup>6</sup> ; increase in emesis latency and decrease in emesis frequency in "early vomiting" squirrel monkeys <sup>11</sup> ) No (increased MS intensity 24-48hrs post exposure <sup>6</sup> ; decrease in emesis latency and increase in emesis frequency for 5 days in "late vomiting" squirrel monkeys, after 5 days habituation became effective but only returned emesis latency and frequency to initial exposure values (e.g. no overall gain) <sup>11</sup> )
2 days	Yes (MS significantly decreased for each exposure across 3 exposures <sup>3</sup> ; MS significantly decreased in 2 <sup>nd</sup> and 3 <sup>rd</sup> exposures compared to 1 <sup>st</sup> exposure, but no significant decrease between 2 <sup>nd</sup> and 3 <sup>rd</sup> exposures <sup>4</sup> ; recommended ISI minimum <sup>3,4,5,6</sup> )
3 days	Yes (suggested <sup>5</sup> ; immediate post exposure SSQ disorientation subscale score and MS intensity 24-48hrs post exposure <sup>6</sup> )
4 days	Yes (suggested <sup>5</sup> ) No (No significant reduction in MS <sup>3</sup> )
5 days	Yes (suggested max ISI for reduction of MS <sup>5</sup> )
7 days	Yes (adaptation retained <sup>7</sup> ; decreased for each exposure across 3 exposures, particularly SSQ disorientation subscale, but significance not reported <sup>8</sup> )
18 days	No (increase in immediate post exposure MS scores, but a decrease in 24-48hr post exposure MS scores <sup>6</sup> )
24 days	No (no significant reduction in MS <sup>3</sup> )
30 days	No (no retention of adaptation <sup>7</sup> )

Table 3. 1 = Golding and Stott (1997). 2 = Lackner and Graybiel (1982). 3 = Stern et al. (1989). 4 = Hu, (1990). 5 = Kennedy et al. (1987). 6 = Watson (1998). 7 = Kennedy, Tolhurst, & Graybiel (1965). 8 = Cobb et al. (1999). 9 = Singer, Ehrlich, & Allen (1998). 10 = Dizio and Lackner (1997). 11 = Wilpizeski, Lowry, Miller, Smith, and Goldman (1987).



In summary, past studies have demonstrated that different ISI and REIWS can either exacerbate or diminish the adverse effects of visually induced motion sickness. Thus, further evaluation of this variable has the potential to lead to the identification of between exposure and between session durations that may be optimal for facilitating the mitigation of side-effects.

#### Stable High Intensity vs. Incremental Intensity: Manipulating Velocity

In regards to incrementing stimulus intensity via manipulation of velocity, Reason and Graybiel's (1970) study on the ideal stepwise increment for adaptation to Coriolis forces associated with head movements in the SRR provides a strong foundation. The important aspect of their findings is that increasing the velocity of rotation does in fact increase the stimulus intensity, as evidenced by the power function relationship they discovered between total number of head movements required to achieve adaptation and an increase in velocity. Studies manipulating velocity have also been done in optokinetic drums in an effort to assess at what velocity vection is most saturated. Kennedy, Hettinger, Harm, Ord, and Dunlap (1996) looked at a range of velocities from 20 deg/sec to 210 deg/sec in 10 deg/sec intervals. They found that circular vection for the spatial frequency and optokinetic drum dimensions they were using became more saturated as velocity increased up to 60 deg/sec, at which point it plateaued until it decreased above 160 deg/sec. In addition, they found that latency of circular vection onset decreased as velocity increased up to 160 deg/sec. In essence, Kennedy et al's (1996) findings demonstrate that intensity of the stimulus created in an optokinetic drum can be manipulated with a fair amount of control by adjusting velocity. Graaf, Wertheim,



Bles and Kremers (1990) further support these findings by suggesting that angular velocity, not temporal frequency, determines circular vection.



## HYPOTHESES

Based on the literature review conducted, a set of primary and secondary hypotheses were developed. The hypotheses for this study are as follows.

### Primary Hypotheses

The first hypothesis deals with the expected differences between non-incremental and incremental regimens. Dual process theory of neural plasticity suggests that as stimulus intensity (e.g. sensory conflict created by the optokinetic drum) increases, sensitization will gradually dominate the depression opponent process, subsequently prolonging the process of acclimation and intensifying the sensory conflict signal driving subjective sickness. Dual process theory also suggests that individuals exposed to lower stimulus intensity should be able to achieve a more complete state of acclimation, thereby increasing the likelihood of negative aftereffects (e.g. postural instabilities) during the reacclimation period. From this the following is hypothesized.

H<sub>1</sub>: It is hypothesized that participants in the adaptation and habituation regimens will experience more intense side-effects (as measured by the SSQ), have a faster rate of side-effects intensification (e.g. obtain increasing demarcations of subjective sickness estimates earlier in the exposure duration), and demonstrate less postural instability immediately post-exposure than their incremental counterparts.



H<sub>0</sub>: There will be no significant differences between the adaptation and habituation regimens and their incremental counterparts with respect to side-effects intensity, rate of onset, and immediate post-exposure postural instability.

The second hypothesis examines expected differences between exposures in habituation-based regimens. Research has shown that previous experience can affect the excitability of a neuron (Klein & Kandel, 1978, Kanz et. al., 1979; Frost et al., 1988; and Trudeau & Castelluci, 1993), even if the previous experience did not cause plasticity (Marcus et al., 1988; Fischer et al., 1997). This capability for memory and repeated transitions between altered and real world sensory environments should hasten the recalibration of one's senses (Welch, 1978; Reason, 1975). Thus with each subsequent exposure, the traces associated with that particular altered sensory environment should be retrieved and consolidated more rapidly. This has led to the following hypothesis.

H<sub>2</sub>: It is hypothesized that participants in the habituation and incremental habituation regimens in their repeated exposures will experience significantly less intense side-effects, have a faster rate of acclimation, and manifest less postural instability than in their first exposure.

H<sub>0</sub>: There will be no significant differences between the repeated exposures and first exposure for the habituation and incremental habituation regimens with respect to side-effects intensity, rate of acclimation, and immediate post-exposure postural instability.



### Secondary Hypotheses

The third hypothesis pertains to withdrawal rates and latency of withdrawal from the optokinetic drum due to side-effects. DPT suggests that by utilizing a low intensity stimulus in the incremental regimens (e.g. incremental adaptation and incremental habituation) theoretically one is allowing the depression opponent process to be more influential over the net outcome than the sensitization opponent process. Due to a lack of strength in the sensitization opponent process, a lower intensity sensory conflict signal should be produced. Assuming an equal distribution of susceptibility among the participants in each condition, the following hypothesis is provided.

H<sub>3</sub>: It is hypothesized that significantly more participants will not complete their exposure duration in the adaptation and habituation regimens than participants in their respective incremental counterparts. It is also hypothesized that among the participants who withdraw from exposure, participants in the adaptation and habituation regimens will do so significantly earlier in the exposure than participants in their incremental counterparts.

H<sub>0</sub>: There will be no significant differences between the adaptation and habituation regimens and their incremental counterparts with respect to withdrawal rate and time to withdrawal.

The fourth hypothesis relates to the work of Wilpizeski, Lowry, Miller, Smith, and Goldman (1987) who found that repeated exposures had different effects on emesis in squirrel monkeys based on their predisposition for motion sickness susceptibility. In essence, they found that squirrel monkeys becoming intensely ill accompanied by a short onset latency benefited from repeated exposures, whereas squirrel monkeys becoming



moderately ill with a moderate latency of onset did not benefit from repeated exposures. Based on these findings the following hypothesis is presented.

H<sub>4</sub>: It is hypothesized that participants in the habituation regimen who experience high intensity sickness in their first exposure will show a significant decline in sickness over successive exposures. It is also hypothesized that participants who experience moderate intensity sickness in their first exposure will continue to experience moderate sickness over successive exposures.

H<sub>0</sub>: There will not be a significant decline in sickness between the first and successive exposures for participants in the habituation regimen who show high sickness in their first exposure.

The final hypothesis is in regard to rate and amount of acclimation as a function of stimulus intensity and level of control. Dual process theory states that a low intensity sensory discrepancy stimulus should allow more complete acclimation to that sensory discrepancy because the sensitization opponent process has less influence over the net outcome than the depression opponent process. Therefore, the final hypothesis presented below is as follows.

H<sub>5</sub>: It is hypothesized that participants in the incremental habituation regimen will have significantly lower sickness with repeated exposures than their habituation counterparts. It is also hypothesized that participants in the incremental habituation regimen will have a significantly faster rate of acclimation over repeated exposures in comparison to their habituation counterparts.



$H_0$ : There will be no significant differences over repeated exposures between the habituation and incremental habituation regimens with respect to magnitude of sickness or rate of acclimation.



## METHOD

The suggestions born out of the literature review for ISI and velocity can be empirically investigated by applying them to the 2 by 2 framework (see Table 2) that guided the previous section. This allows empirical investigation of the use of an adaptation regimen, habituation regimen, incremental adaptation regimen, and incremental habituation regimen to see which of these regimens may have the greatest impact in mitigating visually induced motion sickness. Table 4 presents a synopsis of the experimental design that allows comparison among the regimens of adaptation, habituation, incremental adaptation, and incremental habituation.

Table 4. Synopsis of experimental design. N =40

	<b>Adaptation</b>	<b>Habituation</b>
<b>Stable, High Intensity</b>	<ul style="list-style-type: none"> <li>• 1 exposure</li> <li>• Exposure duration = 35 minutes</li> <li>• ISI/REIWS = 0</li> <li>• Velocity = 60 deg/sec</li> <li>• n = 10</li> </ul>	<ul style="list-style-type: none"> <li>• 3 exposures</li> <li>• Exposure duration = 5mins Session 1, 10mins Session 2, 20mins Session 3</li> <li>• ISI = 2 days</li> <li>• Velocity = 60 deg/sec</li> <li>• n = 10</li> </ul>
<b>Incremental Intensity</b>	<ul style="list-style-type: none"> <li>• 1 exposure</li> <li>• Exposure duration = 35 minutes</li> <li>• ISI/REIWS = 0</li> <li>• Velocity = 15 deg/sec, 30 deg/sec, 60 deg/sec</li> <li>• n = 10</li> </ul>	<ul style="list-style-type: none"> <li>• 3 exposures</li> <li>• Exposure duration = 5mins Session 1, 10mins Session 2, 20mins Session 3</li> <li>• ISI = 2 days</li> <li>• Velocity = 15 deg/sec, 30 deg/sec, 60 deg/sec</li> <li>• n = 10</li> </ul>



### Adaptation & Stable, High Intensity

This scenario allows empirical inquiry of a pure adaptation regimen for mitigating VIMS, the most common regimen used in motion sickness research. The participant is exposed to the full intensity of the VIMS provoking stimulus by partaking in one long exposure (e.g. 35 minute exposure duration) and given maximum velocity (e.g. 60 deg/sec). The selection of a 35 minute duration is discussed in a latter section titled "Selection of Duration: Effect of Duration on Side-effects."

### Habituation & Stable, High Intensity

In this scenario the utility of a habituation regimen for mitigating VIMS is being investigated. The participant will be exposed to the full intensity of the VIMS-provoking stimulus over three exposure sessions. Participants will be exposed to 60 deg/sec for 5 minutes the first exposure, 10 minutes the second exposure, and 20 minutes the third exposure. The ISI for this condition will be 2 days based on its effectiveness in other VIMS research (Stern et al., 1989; Hu, 1990) as well as its demonstrated utility in other sensory environments (Watson, 1998) and recommendations in the U.S. Navy's simulator sickness guidelines (Kennedy et al., 1987). The selection of the incremented durations is discussed in a latter section titled "Selection of Duration: Effect of Duration on Side-effects."

### Incremental Adaptation

This scenario allows empirical inquiry of an incremental adaptation regimen for mitigating VIMS. The participant is exposed to increasing stepwise increments in



intensity of the VIMS-provoking stimulus within one 35-minute exposure duration. To manipulate intensity of the VIMS-provoking stimulus all participants are given graduated increases in velocity at the same time points in the exposure duration. The first level of velocity in the profile is 15 deg/sec and extends from baseline to baseline +5 minutes. The second level of velocity in the profile is 30 deg/sec and extends from baseline +5 minutes to baseline +15 minutes. The third and final level of velocity is 60 deg/sec and lasts from baseline + 15 minutes to baseline + 35 minutes. Transitions to increased levels of velocity in the incremental adaptation profile are chosen to be consistent with the incremental habituation regimen.

### Incremental Habituation

In this scenario the utility of an incremental habituation regimen for mitigating VIMS is being investigated. The participant will be exposed to increments in the intensity of the VIMS provoking stimulus over three exposure sessions. Once again, varying velocity will manipulate intensity in this condition. The profile of the increments in velocity will follow the profile discussed in “Incremental Adaptation” above. However, the transition to the next increase in level of velocity will occur across exposures, with exposure durations lasting 5 minutes in session 1; 10 minutes in session 2; and 20 minutes in session 3. Therefore, participants will only have the first level of velocity in their first exposure, the second level of velocity in their second exposure, and full velocity in their third exposure. The ISI for this condition will be 2 days to be consistent with the habituation regimen and for reasons explained in the “Habituation & Stable, High Intensity” section.



### Selection of Duration: Effect of Duration on Side-effects

A pilot study was conducted to determine exposure duration. Pilot data used to solidify experimental procedures was gathered on 10 participants using 45-minute exposure durations. The data revealed that those participants who were susceptible to VIMS dropped out prior to 35 minutes of continuous exposure and that those participants who were not susceptible complained of boredom, fatigue, severe eye strain and loss of attentiveness beyond the 35-minute mark. These findings are not surprising considering the standard exposure duration for VIMS work in optokinetic drums is usually no longer than 15 minutes (Hu & Hui, 1997; Stern, Hu, Vasey, & Koch, 1989) and in one other case has been as long as 30 minutes (Webb & Griffin, In press). Therefore, the overall exposure duration for the adaptation and incremental adaptation regimens was set at 35 minutes. Furthermore, 35-minute exposure duration is congruent with envisioned exposure durations for mission rehearsal in US Navy virtual environments.

For the incremental adaptation condition, increments in velocity were 15 deg/sec for the first 5 minutes, 30 deg/sec for the next 10 minutes, and 60 deg/sec for the remaining 20 minutes. This profile of velocity and time was chosen based on the overall cap of 35 minutes for the constant velocity conditions and the findings of Reason and Graybiel (1970) that a power function relationship exists between a 1RPM step in velocity in the SRR (i.e. a 6 deg/sec increase in velocity) and the total number of head movements required to achieve adaptation.

The exposure durations of the habituation and incremental habituation regimens followed the profile of the incremental adaptation condition, except that the 35 minutes was portioned across 3 exposures. The first exposure was 5 minutes, second exposure 10



minutes, and third exposure 20 minutes, each separated by a 48 hour intersession interval. These durations were based on the same logic as that presented for the duration of each increment in the incremental adaptation regimen. In essence, as stimulus intensity increases, the amount of time needed to acclimate is likely a power function. In this case, adhering to a power function was prohibitive and thus a mere doubling of exposure duration per increment in stimulus intensity was the next best solution.

As noted above, the pilot study results had vast ramifications on the experimental design of this research. Foremost, it established a ceiling on exposure duration that could not be exceeded without introducing confounds (e.g. boredom, fatigue, severe eye strain and loss of attentiveness), particularly among the non-susceptible participants. This, in turn, necessitated a revamping of exposure durations and increment step size for the incremented treatments to provide adequate time to acclimate. Finally, it has made some across treatment comparisons (i.e. adaptation vs. habituation; incremental adaptation vs. incremental habituation) infeasible due to the incrementing of exposure duration. This issue is covered in greater detail in the results section.

### Participants

The sample population consisted primarily of college students ranging in age from 19-31 years old with a mean age of 22 and standard deviation of 3 years. The overall sample size was  $N=40$  with  $n=10$  for each of the treatments (i.e. Adaptation, Incremental Adaptation, Habituation, & Incremental Habituation). The subject variables, gender and susceptibility to motion sickness (note: susceptibility to motion sickness is hereafter referred to as “susceptibility”) were equally distributed overall and within each



treatment. This resulted in a male sample size of  $N_M=20$  overall and  $n_M=5$  within each treatment, and female sample size of  $N_F=20$  overall and  $n_F=5$  within each treatment. Participants were classified as either high or low susceptibles based on their Motion History Questionnaire (Kennedy & Graybiel, 1965) (MHQ) score calculated from a scoring key developed by the experimenter specifically forvection (see Appendix). The upper bound for low susceptibles was a score of 2; participants with scores greater than 2 were deemed high susceptibles. This resulted in a low susceptibles sample size of  $N_L=20$  overall and  $n_L=5$  within each treatment, and a high susceptibles sample size of  $N_H=20$  overall and  $n_H=5$  within each treatment.

### Apparatus

The stimulus for this experiment was an optokinetic drum measuring 6ft high and 7ft in diameter powered by a 31 gear reduced 1800rpm motor. The drum was suspended 1ft from the ceiling leaving it 2ft off of the ground. A chair was mounted on a 2ft high platform inside the drum to place the participants' eye level in the middle of the drum's height. The visual stimulus inside the optokinetic drum was a wallpaper pattern that resembles 1" to 2" wide waves in various hues of blue. Finally, a closed circuit camera was mounted above the drum to monitor participants, and a push button was provided to the participants for indicating whenvection was experienced.

An optokinetic drum was chosen as an appropriate testbed for basic VE research for several reasons. First, both optokinetic drums and VEs have the potential to produce VIMS in susceptible individuals. It has also been reported that as our ability to enhance the sense ofvection in VEs has improved, the extent and degree of sickness reported has



increased (Kennedy & Stanney, 1996). Furthermore, individuals who do not experience vection during exposure rarely report side-effects (Hettinger et al., 1990). Another reason for utilizing an optokinetic drum is that it allows one to study the specific effects of vection, a sensation not only thought to be a key component in sickness (Kennedy & Stanney, 1996), but also “presence” (Kennedy, personal communication, 2001) (i.e. a sense of immersion in a VE). Finally, using an optokinetic drum affords precise control over stimulus intensity via setting and a maintained defined velocity.

Other experimental apparatus include the SSQ, MHQ, Reason and Brand’s Motion History Questionnaire (RBMHQ) and a Neurocom SMART BalanceMaster™ (SBM). The SBM is a device for objectively measuring postural stability that utilizes a force plate with four load sensors to measure amplitude and velocity of sway and has a visual surround to eliminate visual cues. The device also includes a harness system for ensuring the safety of the user in the event of a fall. The SBM has a suite of six tests to assist diagnosis of postural stability problems, five of which are used in this experiment. The goal of all the tests is for the participant to quietly stand as stable and upright as possible. Test 1 asks the participant to keep his/her eyes open and the force plate is stationary. Test 2 has the participant close his/her eyes and the force plate remains stationary. Test 3 was not used, but test 4 has participants keep their eyes open, and the platform dips fore and aft in response to the participants’ fore-aft postural sway. Test 5 requires participants to close their eyes while the force plate dips fore and aft in response to the participants’ fore-aft postural sway. Finally, test 6 asks participants to keep their eyes open while both the visual surround and force plate sway dip fore and aft in response to the participants’ fore-aft postural sway.



### Procedure

Before commencing the experiment, participants were asked to sign an informed consent form and an agreement that they would not to operate a motor vehicle, heavy machinery, or a bicycle within one hour of leaving the experimental facility. After this, participants were given a set of instructions explaining the experimental condition they have been assigned to and how the day's events would progress. Upon reading the instructions, they were asked to complete the SSQ, MHQ, RBMHQ, and the aforementioned 5 postural stability tests on the SBM twice.

After completing the pre-exposure tasks, participants entered the optokinetic drum for their assigned exposure duration. During the exposure duration, participants in the adaptation and incremental adaptation conditions were asked to give verbal responses to scored items on the SSQ at baseline +5 minutes and baseline + 15 minutes to assess subjective state of well-being. Upon completion of the exposure duration, or upon dropout, participants were asked to immediately fill out a post-exposure SSQ and complete the set of postural stability tests. Participants filled out the SSQ and completed the postural stability tests again at post +15 minutes, and just the SSQ at post +30 minutes. If the participants were deemed back to baseline levels of side-effects and postural stability as assessed by the SSQ and SBM results, then they were debriefed and free to leave the facility. Participants not exhibiting baseline side-effects and postural stability levels were kept for further monitoring and alternative means of travel home were arranged.



## RESULTS

Analyses were conducted using nonparametric statistics after results from the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality indicated that the data for the various dependent variables were significantly different from the normal distribution at the .05 level. The primary statistics used for analyses were Mann-Whitney U, Kruskal-Wallis, Spearman's Rho, and Sign Test; alpha was set at .05 for all analyses. In addition, multiple linear regression was used solely for model fitting.

### SSQ Total Scores

Mann-Whitney U statistic was utilized to detect differences between the Adaptation (A) and Incremental Adaptation (IA) regimens with respect to SSQ total score. Data was analyzed for each sampling point during their exposure (i.e. baseline, baseline +5mins, baseline +15mins, post 0mins, post 15mins, & post 30mins) and a significant difference was found between A and IA at baseline +5mins ( $p=.025$ ). At baseline +5mins the A regimen had a mean score of 34.78 (27.37) and IA had a mean score of 10.47 (9.13). A Sign Test on the differences between these two treatments at each sampling point except baseline did not result in a significant finding. Figure 2 depicts the time course of sickness as measured by SSQ total score (SSQTS) at each of the sampling points.



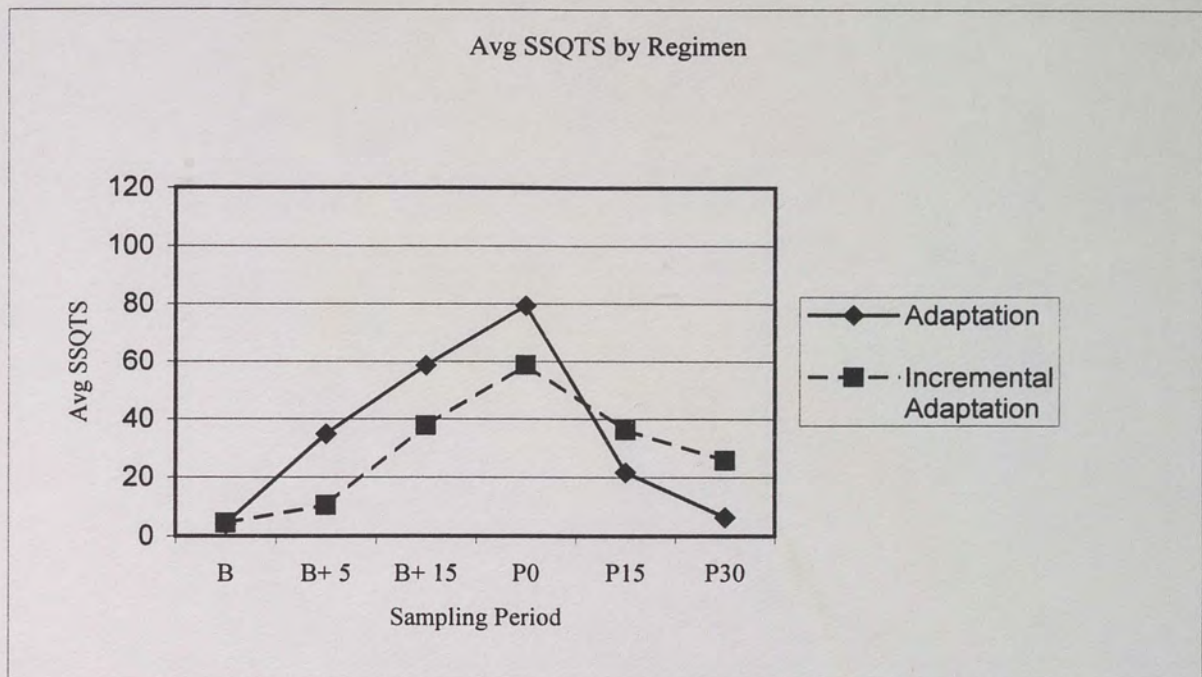


Figure 2. Average SSQ total score (SSQTS) for Adaptation and Incremental Adaptation regimens across the sampling period.

Mann-Whitney U statistic was also utilized to detect differences between the Habituation (H) and Incremental Habituation (IH) regimens with respect to SSQTS. Data was analyzed for each sampling point across all 3 exposures (i.e. baseline, post 0mins, post 15mins, & post 30mins) and no significant differences were found between the H and IH regimens. However, a Sign Test did reveal a significant difference ( $p = .002$ ) between the two treatments when analyzing across all sampling points except sessions 1, 2, and 3's baseline scores. Figure 3 depicts the time course of sickness as measured by SSQTS at each of the sampling points.



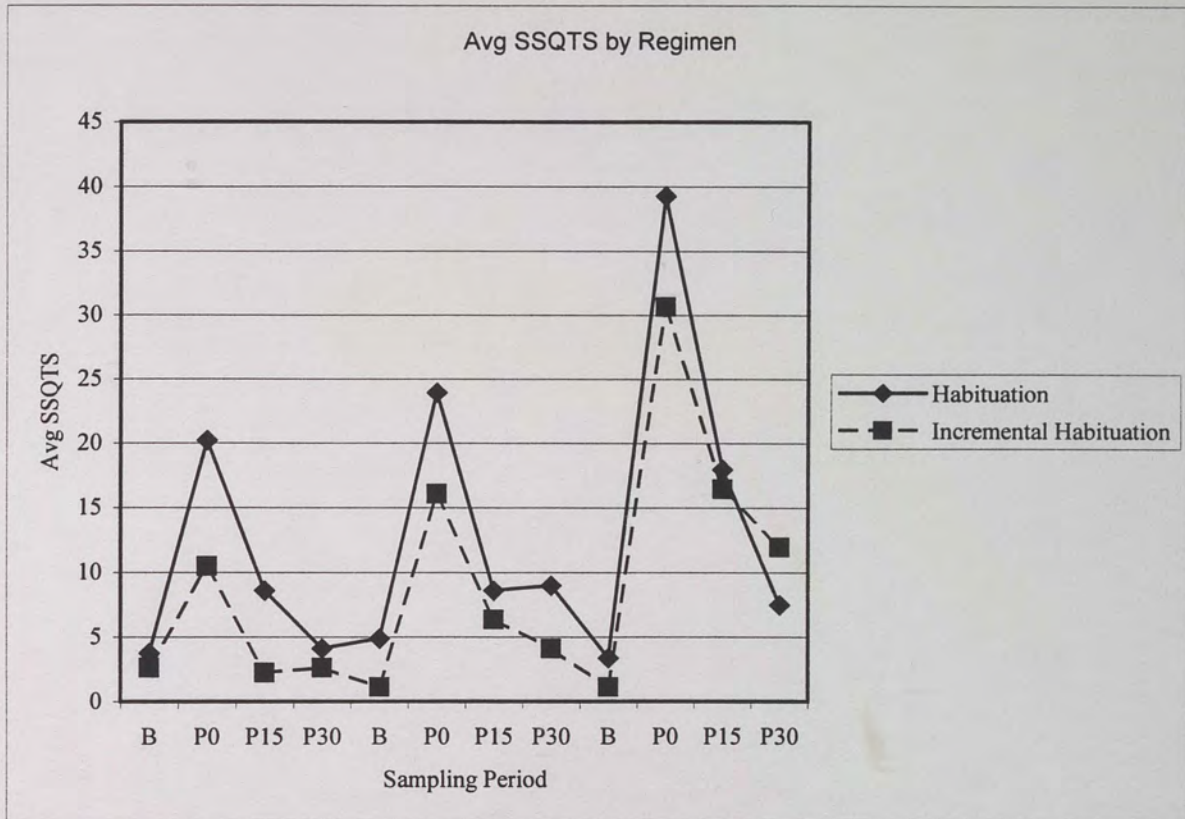


Figure 3. Average SSQ total score (SSQTS) for Habituation and Incremental Habituation regimens across the sampling period for all three exposures.

Data from the H and IH regimens were also analyzed for differences among the immediate post exposure (i.e. P0) SSQTS scores across the 3 exposures. Analysis of the data using the Kruskal-Wallis statistic revealed no significant differences among the immediate post exposure SSQTS for both H and IH regimens.

#### Postural Instability Measures

Previously, Kennedy and Compton (2001) had performed a study that investigated the metric properties of the Neurocom Smart BalanceMaster (SBM) used in this study. One of their findings was that the standard deviation of change in center of gravity along the y-axis (i.e. fore-aft weight shift) was mostly independent of participant size, whereas sway calculated by the SBM was confounded by participants' height and



weight. Furthermore, they found that when the standard deviation of change in center of gravity along the y-axis (SDy) was corrected for height and weight it proved superior to SBM's sway metric in regards to reliability. The increase in reliability is important because it allows the three trials per SBM condition to be averaged together as a single data point per condition per administration. As a result, SDy has been used in these analyses instead of sway.

Before commencing detailed analyses on differences between regimens or sessions, test-retest reliability was ascertained via intertrial correlation for SBM conditions 4, 5, and 6 in the second baseline administration of session 1. The reason for using the second baseline administration is that both Kennedy and Compton (2001) and the current data set demonstrated a practice effect where performance essentially leveled out by the second test administration. Table 5 displays the intertrial correlations for SBM conditions 4, 5 and 6 from the second baseline administration of session 1. All correlation coefficients were significant at the .05 level and are values for Spearman's Rho.



Table 5. Intertrial correlations for all regimens for SBM conditions 4, 5, and 6.

SBM Condition	Correlations for A & IA Regimens			
	Average	Trial 1-2	Trial 1-3	Trial 2-3
4	.588	.711	.418	.636
5	.577	.693	.493	.544
6	.651	.624	.741	.587
SBM Condition	Correlations for H & IH Regimens			
	Average	Trial 1-2	Trial 1-3	Trial 2-3
4	.635	.503	.701	.700
5	.646	.570	.653	.715
6	.520	.427	.423	.710

Posture data for the A and IA regimens were analyzed for differences between the two regimens using the Mann-Whitney U statistic. Findings yielded no significant differences when performing analyses by combining all data points across all conditions and all administrations, combining all data points across all conditions within an administration, nor within a condition within an administration. Figures 4, 5, and 6 graphically display the SDy scores for the A and IA regimens in SBM conditions 4, 5, and 6.



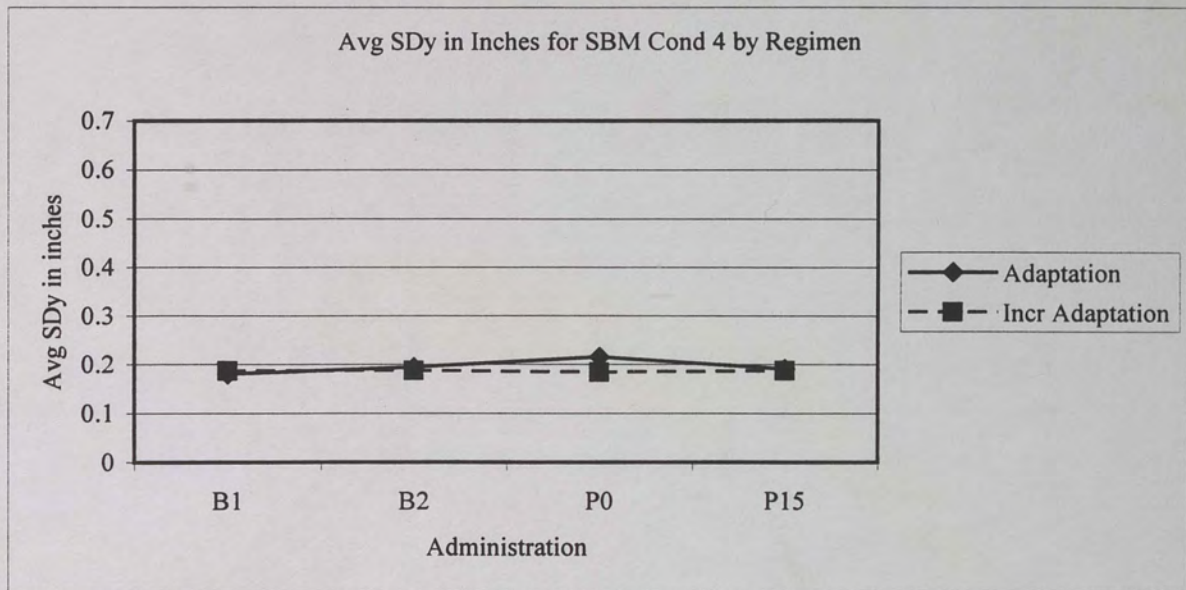


Figure 4. Posture data for A and IA regimens performance on SBM condition 4. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.

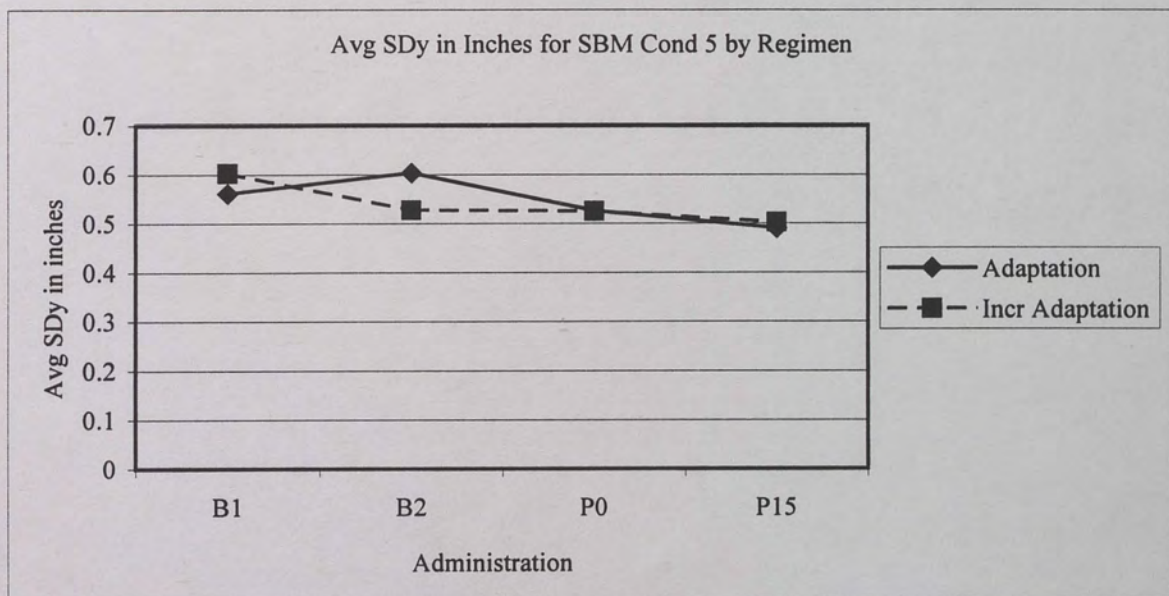


Figure 5. Posture data for A and IA regimens performance on SBM condition 5. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.



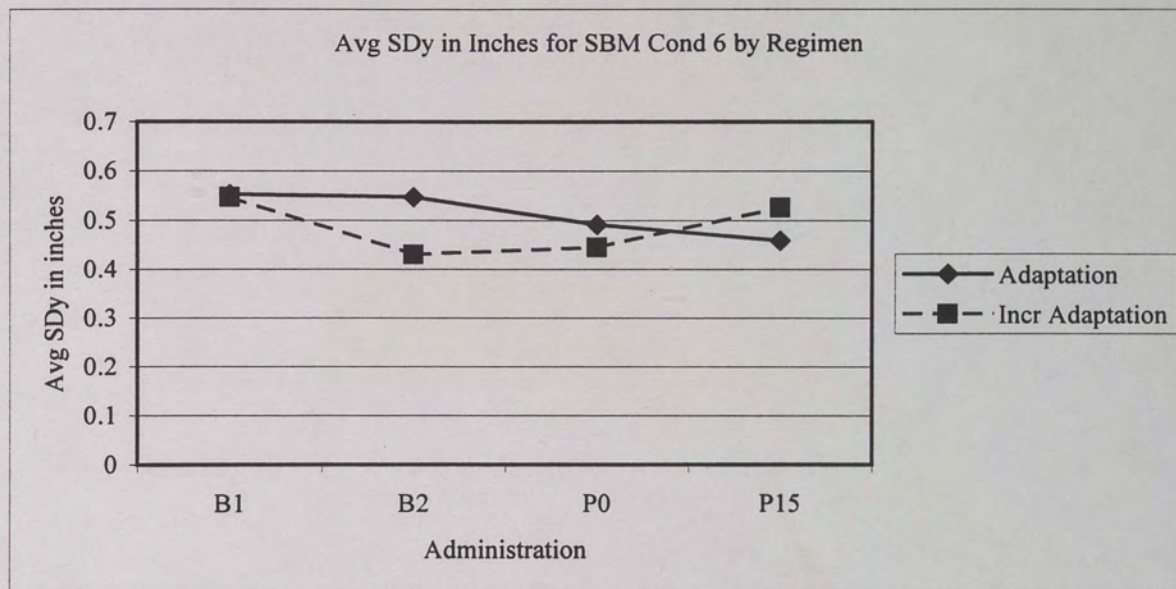


Figure 6. Posture data for A and IA regimens performance on SBM condition 6. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.

Analysis of the posture data for the H and IH regimens revealed that when all data points across all conditions and all administrations were combined, the participants in the H regimen showed significantly ( $p = .001$ ) greater amounts of postural instability than the IH participants. The mean overall SDy score for the H regimen was 0.386 (0.262) and 0.310 (0.166) for the IH regimen. Figures 7, 8, and 9 provide a visual representation of the SDy scores for the H and IH regimens in SBM conditions 4, 5, and 6.



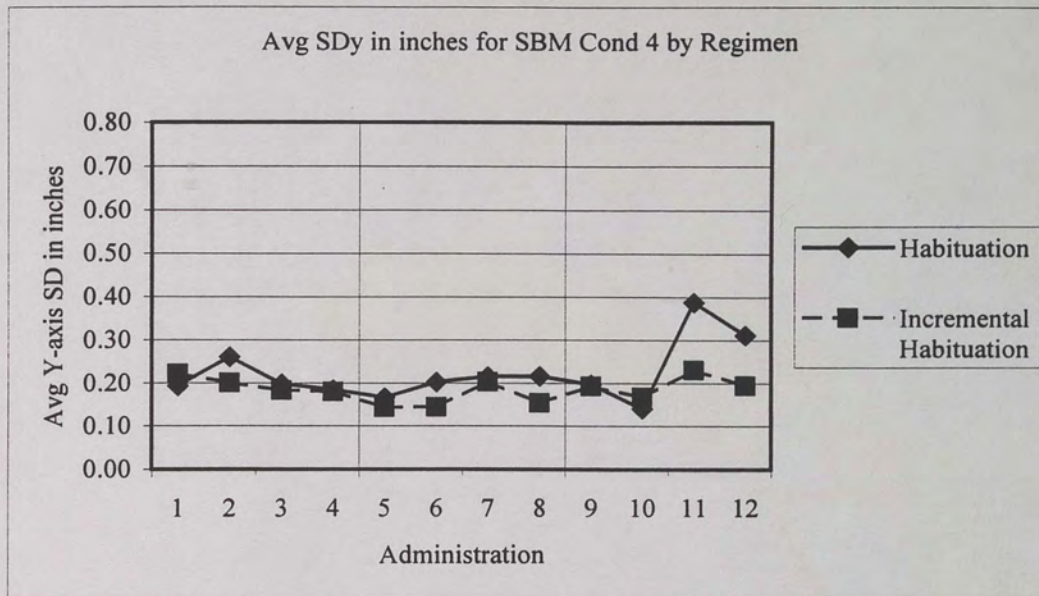


Figure 7. Posture data for H and IH regimens performance on SBM condition 4. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.

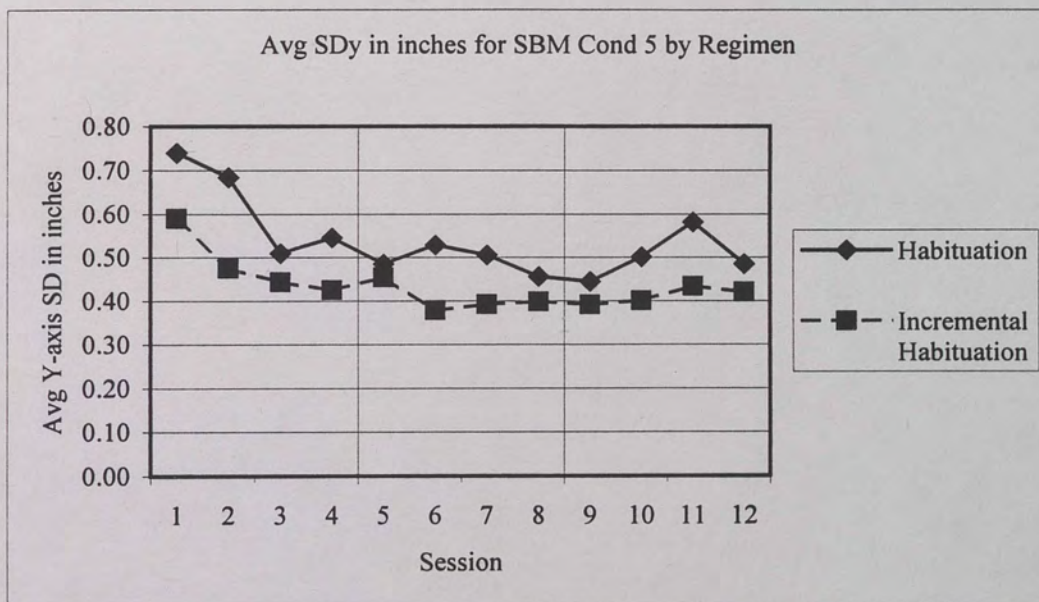


Figure 8. Posture data for H and IH regimens performance on SBM condition 5. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.



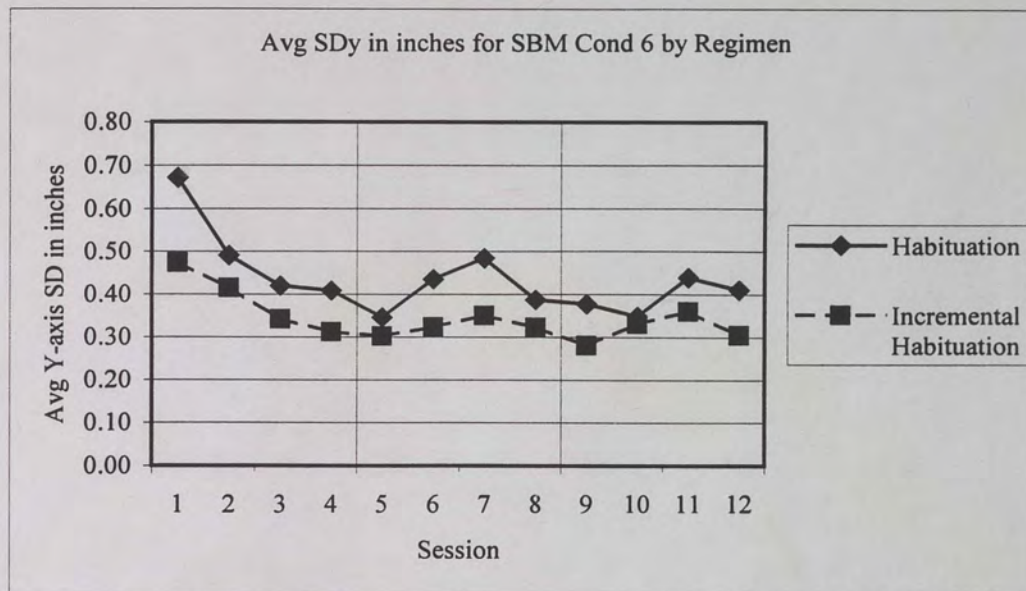


Figure 9. Posture data for H and IH regimens performance on SBM condition 6. Unit of measurement is standard deviation of change in center of gravity along the fore-aft y-axis (SDy) in inches.

Posture data for the H and IH regimens were also subjected to analysis for changes in immediate post exposure postural instability across the three days of exposure. Kruskal-Wallis statistic yielded no significant differences among the immediate post exposure postural instability scores for the three days of exposure in both H and IH regimens.

#### Number of Dropouts, Average Time to Dropout, and Percent of Overall Exposure Duration Completed.

Time to dropout was recorded and subsequently analyzed for dropout rates and percent of overall exposure time completed by participants. Among the participants in the A regimen 50% (5 out of 10) did not complete their assigned exposure duration of 35 minutes. The average time to dropout for those 5 participants that prematurely withdrew was 17.48 minutes with a standard deviation of 8.24 minutes. Average SSQ total score at time of dropout was 107.71 (35.72). In the IA regimen 20% (2 out of 10) did not



complete the 35-minute assigned exposure duration. The average time to dropout for those 2 participants that prematurely withdrew was 16.23 minutes with a standard deviation of 3.31 minutes. Average SSQ total score at time of dropout was 115.94 (63.47). Mann-Whitney U statistic revealed that there were no significant differences between the A and IA regimens with respect to percent of overall exposure time completed. Figure 10 shows the percent of overall exposure duration completed for A and IA regimens.

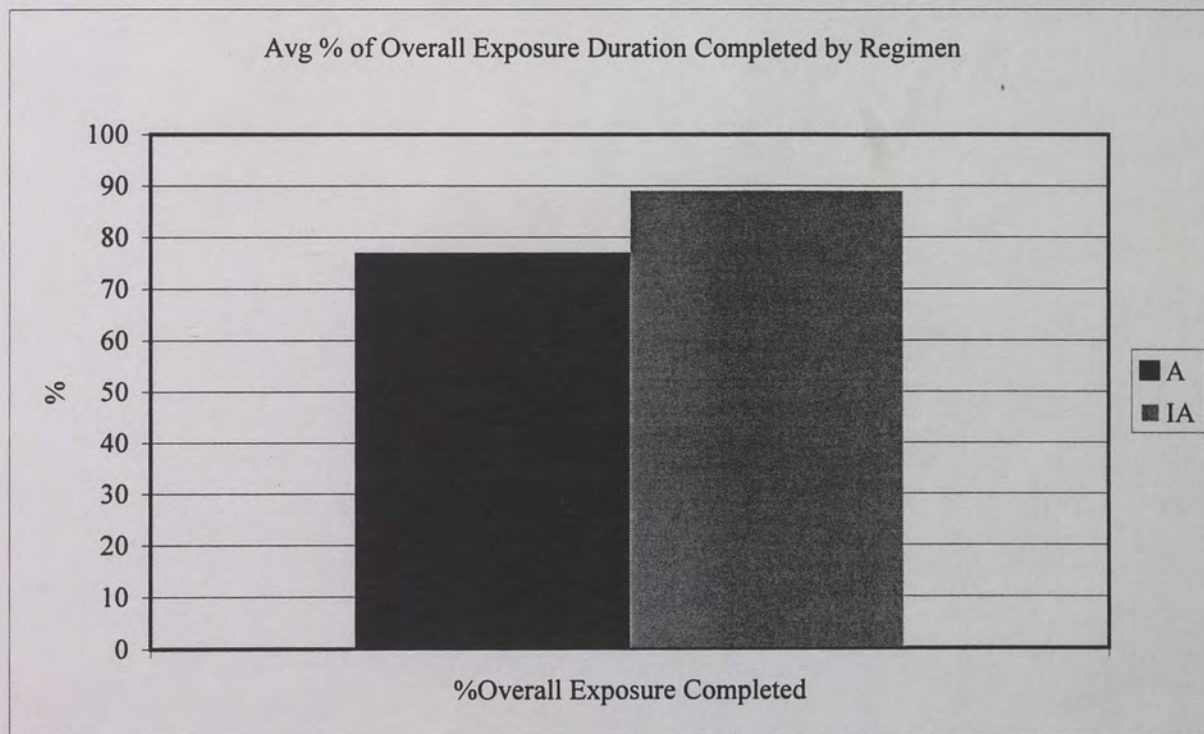


Figure 10. Average percent of overall exposure duration completed for A and IA regimens.

There were no dropouts in H regimen across all three exposure sessions. However, in the IH regimen 20% (2 out of 10) did not complete the 3<sup>rd</sup> exposure duration, which was 20 minutes. The average time to dropout for those 2 participants who prematurely withdrew was 9.28 minutes with a standard deviation of 5.49 minutes.



Average SSQ total score at time of dropout was 61.71 (2.64). Mann-Whitney U statistic revealed that there were no significant differences between the H and IH regimens with respect to percent of overall exposure time completed. Figure 11 shows the percent of overall exposure duration completed for H and IH regimens.

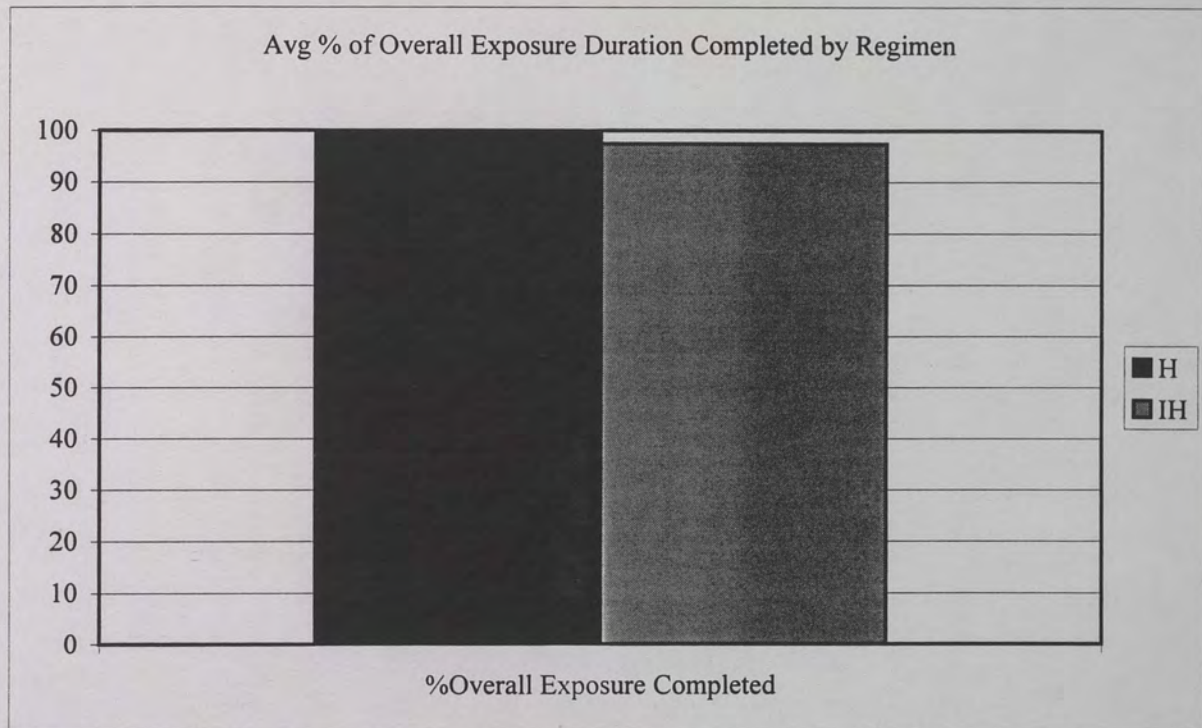


Figure 11. Average percent of overall exposure duration completed for H and IH regimens.

#### Additional Analyses: Motion History Questionnaire (MHQ)

Motion sickness history data were acquired via the MHQ to assure equal distribution of susceptibility among treatments and within the gender subject variable. Analysis of the MHQ data via Mann-Whitney U statistic looked at differences between regimens (e.g. A vs. IA; H vs. IH), gender, and susceptibility. There were no significant differences for the regimen or gender analyses, but there was a significant difference ( $p <$



.0001) between high and low susceptibles. The same results were found for the H and IH MHQ data set where the difference between high and low susceptibles was also significant at  $p < .0001$ .

#### Additional Analyses: Simulator Sickness Questionnaire (SSQ)

Further analyses of the SSQTS revealed interesting results that warrant reporting. SSQTS data for both A and IA and Hand IH data sets were analyzed by gender and susceptibility in addition to the analysis by regimen reported above. Data from the A and IA participants was scrutinized at all sampling periods using the Mann-Whitney U statistic and yielded no significant differences between genders, but did result in significant differences between the high and low susceptibles. SSQTS were significantly different between high and low susceptibles at all sampling periods except baseline. Table 6 provides the means, standard deviations, and p-values for the significant differences between high and low susceptibles across the sampling periods. Figure 12 depicts the differences graphically over time.

Table 6. A& IA SSQTS means and standard deviations for the significant differences between high and low susceptibles; p-value of the significant differences is also reported.

Sampling Period	Mean	Standard Deviation	p-value
Baseline +5mins	L =10.85; H=34.41	L=15.21; H=24.92	.008
Baseline +15mins	L=19.45; H=84.15	L=23.44; H=48.23	.005
Post 0mins	L=31.79; H=106.22	L=33.92; H=45.51	.002
Post 15mins	L=9.72; H=48.25	L=10.31; H=33.38	.002
Post 30mins	L=2.25; H=29.92	L=2.62; H=29.24	.005



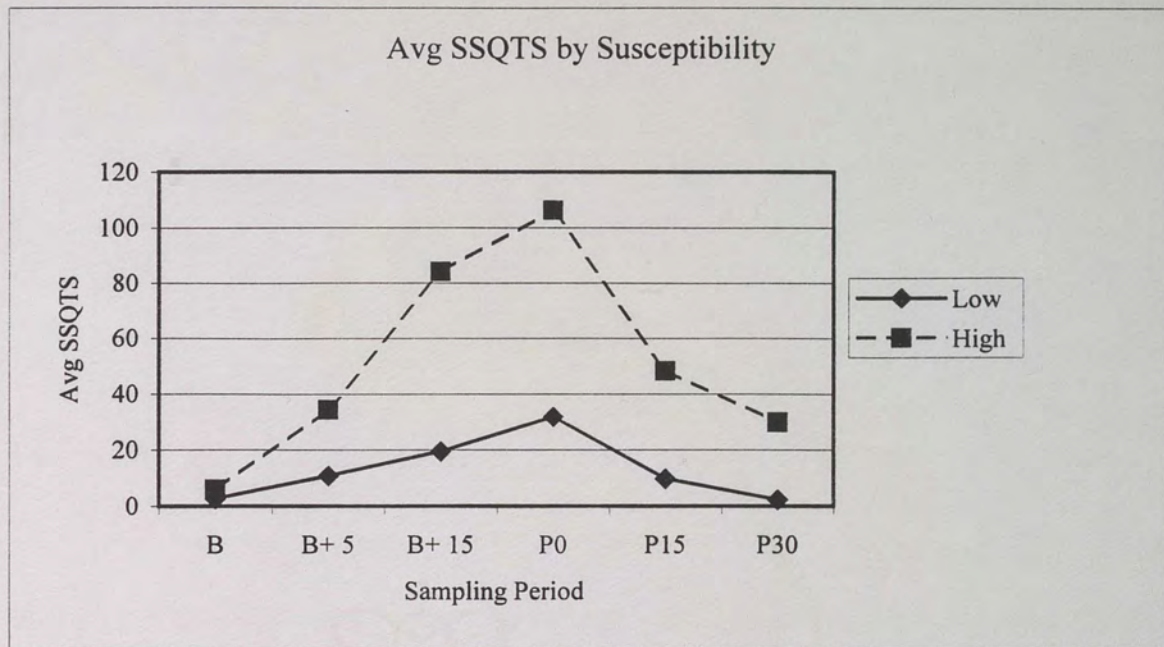


Figure 12. Average SSQTS by susceptibility for participants in the A and IA regimens.

Data from the H and IH participants was examined at all sampling periods using the Mann-Whitney U statistic and yielded no significant differences between genders, but did result in significant differences between the high and low susceptibles. SSQTS were significantly different between high and low susceptibles at baseline in exposure 1, as well as post 0mins, post 15mins, and post 30mins in sessions 2 and 3. Table 7 provides the means, standard deviations, and p-values for the significant differences between high and low susceptibles across the sampling periods. Figure 13 depicts the differences graphically over time.



Table 7. H & IH SSQTS means and standard deviations for the significant differences between high and low susceptibles; p-value of the significant differences is also reported.

Sampling Period	Mean	Standard Deviation	p-value
Baseline Session 1	L=0.75; H=5.61	L=1.58; H=4.75	.012
Post 0mins Session 2	L=9.35; H=30.67	L=11.32; H=19.93	.010
Post 15mins Session 2	L=2.24; H=12.72	L=4.02; H=11.98	.023
Post 30mins Session 2	L=1.12; H=11.97	L=2.52; H=15.55	.040
Post 0mins Session 3	L=17.95; H=51.99	L=18.56; H=35.32	.017
Post 15mins Session 3	L=8.60; H=25.81	L=15.87; H=19.90	.016
Post 30mins Session 3	L=4.49; H=14.96	L=10.40; H=11.43	.009

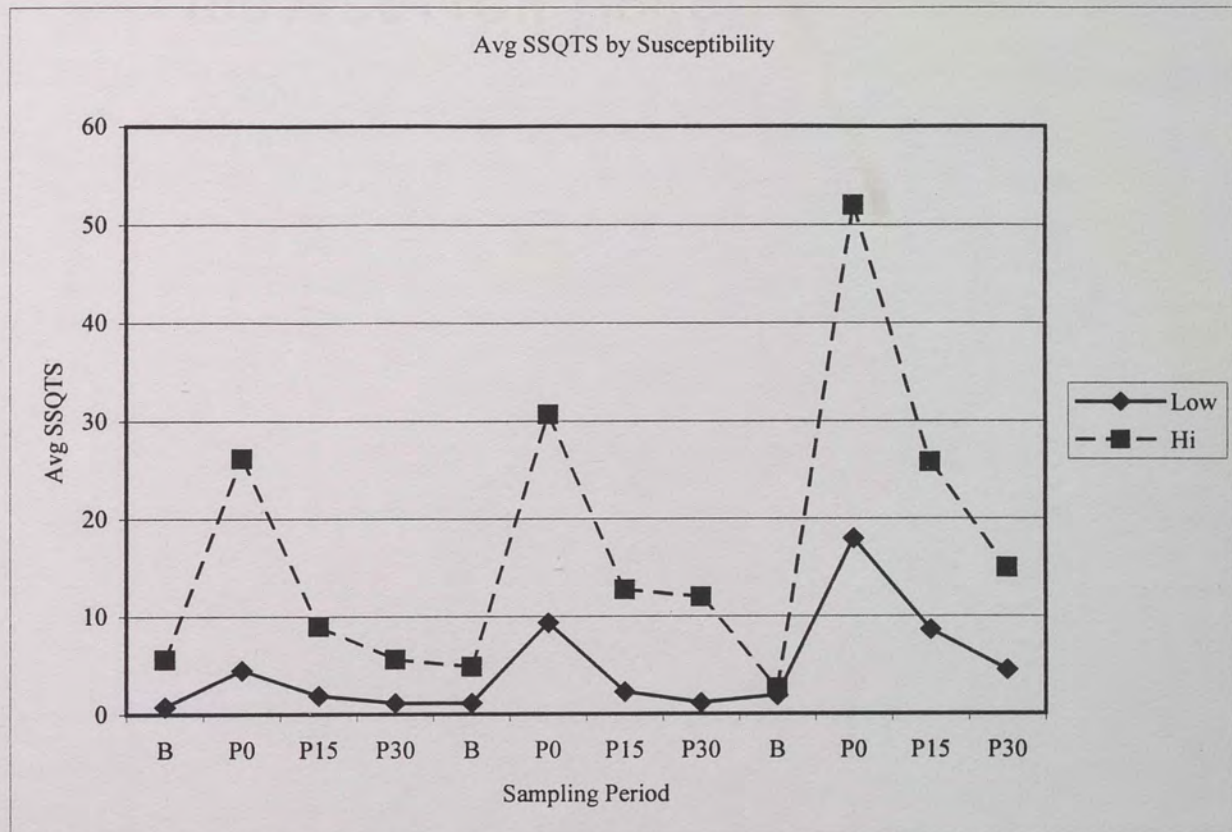


Figure 13. Average SSQTS by susceptibility for participants in the H and IH regimens.

#### Additional Analyses: Multiple Linear Regression

Multiple linear regression was used solely to fit models for predicting SSQTS given combinations of predictor variables selected based on logical and theoretical



support. Attempts at fitting a model to the A and IA data set were less than successful, despite creating a multitude of predictor variable combinations that utilized baseline posture data from Smart BalanceMaster conditions 1, 2, 4, 5, and 6; MHQ score; MHQ score from Reason and Brand's (1975) questionnaire, in particular the overall score for the last 10 years, the score for feeling sick in the last 10 years, and the overall MHQ score; and finally baseline SSQTS. The model with the highest adjusted R square had a value of 0.167 and used a single predictor variable of MHQ score.

Attempts to fit models to the data set comprised of H and IH participants yielded higher adjusted R square values, likely because a history of SSQTS was compiled for the participants. Models were fit to predict SSQTS after sessions 1, 2, and 3. The attempt to fit a model for SSQTS in session 1 yielded the lowest adjusted R square value for the H and IH data set despite creating a multitude of predictor variable combinations that were comprised of session 1 baseline posture data from Smart BalanceMaster conditions 1, 2, 4, 5, and 6; MHQ score; MHQ score from Reason and Brand's (1975) questionnaire, in particular the overall score for the last 10 years, the score for feeling sick in the last 10 years, and the overall MHQ score; and finally session 1 baseline SSQTS. The highest adjusted R square value for predicting SSQTS in session 1 was 0.481 and used a single predictor variable of session 1 baseline SSQTS.

The model for predicting SSQTS in session 2 was an improvement upon the model for SSQTS session 1. The various combinations of predictor variables utilized included session 2 baseline posture data from Smart BalanceMaster conditions 4, 5, and 6; MHQ score; MHQ score from Reason and Brand's (1975) questionnaire, in particular the overall score for the last 10 years, the score for feeling sick in the last 10 years, and



the overall MHQ score; session 1 and 2 baseline SSQTS; and finally SSQTS for post 0mins session 1. A model yielding an adjusted R square of 0.694 was obtained using post 0mins SSQTS from session 1 and MHQ score predictor variables.

Finally, a model to predict SSQTS for session 3 obtained the highest adjusted R square value among the H and IH data set. The various combinations of predictor variables utilized included session 3 baseline posture data from Smart BalanceMaster conditions 4, 5, and 6; MHQ score; MHQ score from Reason and Brand's (1975) questionnaire, in particular overall score for the last 10 years, score for feeling sick in the last 10 years, and overall MHQ score; session 1, 2, and 3 baseline SSQTS; and finally SSQTS for post 0mins from sessions 1 and 2. A model yielding an adjusted R square of 0.888 was created using the post 0mins SSQTS from sessions 1 and 2 as predictor variables. The equation for this model was:  $SSQTS = 6.354 + .749(\text{post 0mins SSQTS session 1}) + .856(\text{post 0mins SSQTS session 2})$ .



## DISCUSSION

The objectives of this research were to empirically validate the utility of an incremental approach for acclimating to visually induced motion sickness, and to demonstrate the benefits of an incremental regimen in comparison to a non-incremented approach for both single and repeated exposures. In achieving these objectives, sub-objectives were also pursued including analyzing gender differences, classifying susceptibility, and a means for predicting likelihood of future episodes of malaise. Below is a discussion of how the findings of this study support and refute the hypotheses set forth and their implications. The additional analyses are interwoven where appropriate for further support and clarification.

Before delving into the hypotheses, an important supplementary analyses should be discussed: MHQ scores. The statistical analyses on MHQ score revealed no significant differences between regimens or genders, but did yield a significant difference between susceptibles. This finding allows discussion of the results pertaining to analyses by regimen, gender, and susceptibility with confidence because the tool (i.e. MHQ) used to equally distribute participants based on susceptibility among the treatments was effective. In other words, the MHQ was capable of identifying high and low susceptible participants, which afforded a balanced, yet random, distribution of susceptibility among the treatments and within the subject variable gender. Therefore, in discussing the



findings here within it can be reasonably assumed that susceptibility has not skewed the data.

#### Hypotheses 1: Differences Between Incremented and Non-Incremented Regimens

Hypotheses 1 focused on the differences between incremented and non-incremented regimens (i.e. A vs. IA; H vs. IH) with respect to intensity of side-effects as measured by the SSQTS, rate of side-effects intensification, and postural stability. In essence, it was hypothesized that the non-incremented regimens would display higher SSQTS scores, a faster rate of side-effects intensification, and greater postural stability than their incremented counterparts. The data for the A and IA regimens yielded statistical results more in tune with hypothesis 1 while data for the H and IH regimens were less supportive.

Regarding SSQTS for A and IA regimens, a significant difference was only found at baseline +5 minutes. The lack of a significant difference immediate post exposure is puzzling on the surface, but becomes disentangled when SSQTS data are viewed in conjunction with dropout data. Recall that in the A regimen, 50% of the participants prematurely withdrew after completing an average of 17.48 minutes of exposure time, half of the assigned exposure duration. Furthermore, 80% of those that withdrew early were high susceptible participants. In comparison, only 20% of the IA participants withdrew ahead of time and both participants were high susceptibles. Therefore, the lack of a significant difference between A and IA regimens with respect to SSQTS immediate post exposure may be due to a higher rate of early termination of exposure shortly after the baseline +15 minutes sampling period by the A regimen participants. In other words, the rate of increase in side-effects experienced by participants in the A regimen was



greater than that of the IA participants, causing participants in the A regimen to end participation on average after 26 minutes of exposure in comparison to 31.2 minutes of exposure for the IA regimen. While no significant differences were found between A and IA with respect to percent of overall exposure time completed, it is likely a difference may have surfaced with a longer exposure duration.

Results from the postural stability data for the A and IA regimens revealed no significant differences between the regimens. The lack of findings may be attributable to a multitude of explanations, but it is likely that a major cause is the sessile nature of an optokinetic drum-based experiment. Optokinetic drums and SRR are similar in that they induce a sensation of circular self-motion and are capable of pseudo-Coriolis and Coriolis effects respectively. However, SRR do induce ataxia upon exiting (Graybiel et al. 1965) as a result of ambulating about the SRR and physical stimulation of the semi-circular canals. Therefore, the minute changes in postural stability observed in this study may be an artifact of participants remaining seated during their exposure preventing physical stimulation of the semi-circular canals.

An interesting spur of this finding is its implication for visually induced motion sickness found in other environments such as non-motion based simulators and virtual environments. SSQTS scores from this study are comparable, if not exceed, SSQTS scores from previous visually induced motion sickness research in simulators and virtual environments. It is possible that simulators and VEs that require minimal physical interaction (e.g. head movements and ambulation) might put participants at lower risk for operationally significant postural disturbances post exposure. While ataxia has been



reported post VE exposure (Kolasinski & Gilson, 1999), the operational significance of these changes is hard to quantify.

The data for the H and IH regimens did not support hypothesis 1 as clearly as the data for A and IA did. In particular, statistical analysis of SSQTS did not result in a statistically significant difference between the regimens, but a difference is evident between the regimens in Figure 3. The SSQTS scores for the H regimen were consistently higher than those of the IH regimen immediately post exposure, suggesting that incrementing stimulus intensity had a positive effect on participants in IH regimen. This is further supported by the significant findings of the Sign Test reported earlier. These gains are more clearly illustrated when the analysis is further decomposed to the level of regimen by susceptibility for the H and IH regimens. Figure 14 depicts the SSQTS for regimen by susceptibility using the H and IH data set; notice the disparity between high susceptibles in the H and IH regimens which are bolstered by a significant ( $p = .002$ ) finding when subjected to the Sign Test.



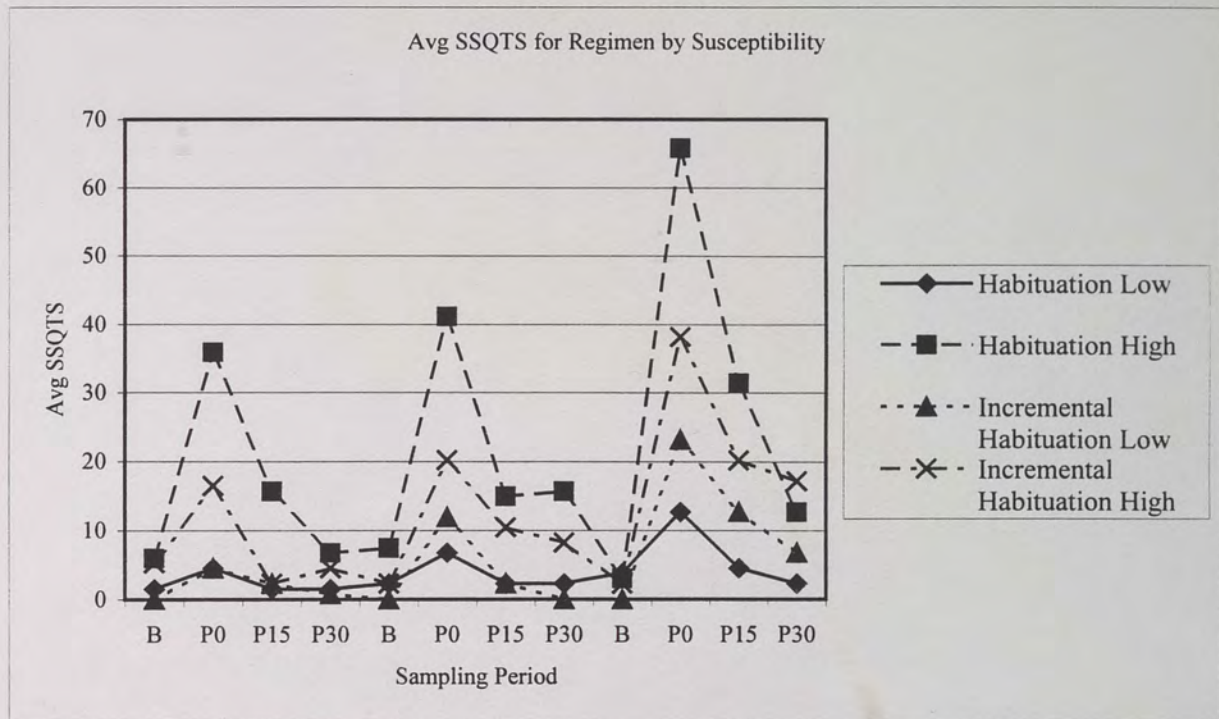


Figure 14. SSQTS for Habituation and Incremental Habituation data broken out as regimen by susceptibility.

The postural data for the H and IH regimens yielded results in antithesis of hypothesis 1. It was speculated that the participants in the incremented treatments would exhibit greater amounts of postural instability than their non-incremented counterparts as a result of completing more of the adaptive process. In essence, the IH participants should be more posturally unstable as a result of the increased rate of acclimation afforded by increments in stimulus intensity. This is what the DPT (Groves & Thompson, 1970) suggests as well as data from the Slow Rotation Room (Graybiel et al. 1965). However, in this study the participants in the H regimen exhibited significantly higher levels of postural instability than the IH participants when all data points across all conditions and all administrations were combined. There is a plausible explanation for this that keeps in line with the DPT. It is feasible to suspect that the participants in the IH regimen were undergoing an accelerated rate of achieving dual adaptation with respect to postural



stability, in comparison to participants in the H regimen. This notion is further supported by the leveling off of postural stability among the IH participants after the first exposure session, whereas the H participants display the expected increase in postural instability immediately post exposure in comparison to baseline in sessions 2 and 3. In essence, these posturography results viewed from the stance of progressing towards dual adaptation are congruent with the underlying logic for hypothesizing greater postural instability among the IH participants; the IH participants are acclimating faster and to a higher degree than H participants.

In summary, hypothesis 1 one was largely supported through statistical differences and apparent trends in the data. Findings from the A and IA regimens were more clear-cut in their support, but results from the H and IH regimens were mostly supportive of the hypothesis. The lone oddity is found in the posturography data for the H and IH regimens, which may actually be a supportive finding when viewed in light of achieving dual adaptation.

#### Hypothesis 2: Effect of Repeated Exposures on H & IH Regimens

Hypothesis 2 was focused on the effects of repeated exposures on SSQTS scores and postural stability. The hypothesis suggested that with each subsequent exposure SSQTS scores and postural instability measures would decrease due to the participants acclimating. This hypothesis was originally put forth with the intention that participants in the H and IH regimens would have three exposures of equal duration; however, due to pilot data, the exposure durations for each session had to be incremented (i.e. 5 minutes in session 1, 10 minutes in session 2, and 20 minutes in session 3). Despite the change in



experimental design, the findings are still relevant from an alternative viewpoint.

Research on visually induced motion sickness in simulators and VEs (Kennedy, Stanney, & Dunlap, 2000) has shown that sickness intensity is a function of duration. In other words, as the duration increases so does the intensity of malaise. Therefore, it would be reasonable to assume that SSQTS and postural stability after each session would be significantly greater than the score preceding it.

Analysis of Data from the H and IH regimens revealed that despite the doubling of duration each subsequent exposure, there were no significant differences across the three exposures for immediate post exposure SSQTS and postural instability measures. This suggests that the H and IH regimens afforded enough acclimation each exposure to mitigate side-effects. In essence, incrementing exposure duration may also be an effective means for suppressing side-effects in a repeated exposures protocol. This finding is in agreement with the work of Hu and Hui (1997) using an optokinetic drum where a group of participants who that closed their eyes at the first sign of malaise required fewer sessions and fewer overall minutes of exposure to acclimate than those not instructed to close their eyes. Hu and Hui suggested that pre-malaise exposure time is key to driving the acclimation process, thereby making it unessential to complete the entire exposure duration. The incrementing of exposure time is akin to this philosophy where participants are gradually exposed to longer and longer durations.

It appears that in a repeated exposures protocol, incrementing exposure duration and incrementing both exposure duration and stimulus intensity are effective means to mitigating side-effects. It is also apparent based on SSQTS scores that the combination of



incrementing both exposure duration and stimulus intensity is more effective than just incrementing exposure duration, possibly speeding attainment of a dual adaptive state.

### Hypothesis 3: Dropout Rates and Time to Dropout, Differences Among Regimens

Hypothesis 3 focused on dropout rates and time to dropout with respect to differences between the incremented and non-incremented regimens. It was hypothesized that significantly more participants would not complete their exposure duration in the adaptation and habituation regimens than participants in their respective incremental counterparts. Furthermore, it was put forth that among the participants who withdrew, participants in the adaptation and habituation regimens would do so significantly earlier in the exposure than their incremental counterparts.

Dropout data between the A and IA participants was previously discussed in the section on hypotheses 1. To summarize the relevant findings, 50% of the participants in the A regimen prematurely withdrew after completing an average of 17.48 minutes of exposure time, half of the assigned exposure duration. Eighty percent of those that withdrew early in the A regimen were high susceptible participants. In comparison, only 20% of the IA participants withdrew early, but did so on average after 16.23 minutes of exposure; both dropout participants were high susceptibles. Clearly the data support the hypothesis in regards to dropout rates, particularly among the highly susceptible participants where dropouts would be expected to occur. Interestingly though, the findings are not supportive of the time to dropout portion of the hypotheses. More specifically, percent of overall exposure time completed failed to yield a significant difference between the regimens; however, the means were in the anticipated direction



with IA regimen completing an average of 89% of overall exposure time and A regimen completing only 76.7%.

Dropout data for the H and IH regimens were a bit more perplexing than data from the A and IA regimens. There were no dropouts in the H regimen across all three exposure sessions, whereas 20% (2 out of 10) of the IH participants did not complete the third exposure duration. The average time to dropout for those 2 participants was 9.28 minutes into the third exposure. The most plausible explanation for this finding is that the IH regimen had two participants that were highly susceptible and slow acclimators. In regard to percent of overall exposure time completed, no significant differences arose and both H and IH regimens excelled achieving 100% and 93.6% completion rates respectively.

In summary, an incremented approach appears to be capable of reducing dropouts among at risk participants in one time exposure protocols; as well, it appears to be effective in prolonging exposure duration completed. On the contrary, in repeated exposure protocols where exposure time is already incremented, incrementing stimulus intensity may not be as useful for reducing dropout rates and prolonging exposure duration completed as it is in a one time exposure. However, if stimulus intensity is the only variable incremented, it may prove effective in a repeated exposures protocol.

#### Hypotheses 4 & 5: Habituation & Incremental Habituation Regimen Participants

These hypotheses, like hypothesis 2, were originally put forth with the intention that participants in the H and IH regimens would have three exposures of equal duration; however, due to pilot data, the exposure durations for each session had to be incremented.



Hypothesis four pertained to participants in the habituation regimen who exhibited high intensity SSQTS scores in their first exposure. It hypothesized that those participants with initial high SSQTS scores would show a significant decline in SSQTS over successive exposures. In addition, it was put forth that participants experiencing moderate intensity SSQTS in their first exposure would continue to experience moderate intensity SSQTS over successive exposures. Hypothesis five stated that participants in the incremental habituation regimen would have significantly lower SSQTS with repeated exposures than their habituation counterparts, as well as a faster rate of acclimation over repeated exposures.

As discussed earlier, SSQTS scores are affected by exposure duration, thereby negating the feasibility of these hypotheses. With respect to hypothesis four, there was no opportunity for decline in SSQTS due to the doubling of exposure duration with each subsequent session. However, the lack of a significant difference between SSQTS across the 3 exposures for the habituation regimen may suggest that incrementing exposure time is an effective means to mitigating side-effects. Hypothesis five was testable, nevertheless, but yielded an insignificant difference between the H and IH regimens with respect to SSQTS. Notwithstanding, the difference between IH and H SSQTS means and the results of the Sign Test were in the direction hypothesized as shown in Figure 3. These findings further reinforce the notion that the combination of incrementing stimulus intensity and exposure time is more effective in minimizing side-effects than just exposure time alone.

In summary, these findings once again support the idea that in a repeated exposures protocol, incrementing exposure duration and incrementing both exposure



duration and stimulus intensity are effective means to mitigate side-effects. It is also apparent that the combination of incrementing both exposure duration and stimulus intensity may be more effective than just incrementing exposure duration, possibly speeding obtainment of a dual adaptive state.

### Gender

An interesting finding in this study was the lack of significant differences between genders with respect to SSQTS. It has long been suggested that females are more susceptible to experiencing more intense motion sickness and obtain higher SSQTS scores (Kennedy, Lanham, Drexler, & Lilienthal, 1995; Kennedy, Lanham, Massey, Drexler, and Lilienthal, 1995; Kennedy, Stanney, Dunlap, & Jones, 1996; Kolasinski, 1996; Rich and Braun, 1996; Kennedy, Drexler, & Harm, 1999). Potential explanations have suggested that women have a larger field-of-view than men (Kennedy & Frank, 1985), that sickness is positively correlated to hormone levels in women (Grunfeld & Gresty, 1998), and that women are more in tune with their bodies and more likely to report maladies (Katz & Criswell, 1996; Koutantji, Pearce, & Oakley, 1998). The results from this study and Park and Hu (1999) suggest a diametric interpretation. The aforementioned citations of SSQTS pertaining to gender did not mention an effort to balance susceptibility across the genders as done in this experiment; thus, it is plausible that past reported differences between genders might be due to a skewing of susceptibility between the genders and not the subject variable of gender.

In essence, no gender effect was found for SSQTS across all regimens and all sampling periods. These findings and other recent findings by Park and Hu (1999) could



be interpreted as a warning to verify that previous and future gender effects are truly due to the subject variable gender and not a skewing of susceptibility within the experimental design.

#### Tools for Identifying At Risk Participants: Susceptibility and Multiple Linear Regression

Care was taken in this experiment to have a balance of susceptibility among the treatments and gender subject variable. The MHQ scoring devised for this experiment was successful in demarcating low from high susceptibles. Of primary importance is the significant difference between high and low susceptibles found for SSQTS across all sampling periods except baseline, with the exception of baseline session 1 for the H and IH participants. Furthermore, significant differences in postural stability were found between high and low susceptibles in the H and IH regimens.

Model-fitting using multiple linear regression was performed on the H and IH regimen data in an effort to predict immediate post exposure SSQ total scores. The various models created revealed that the most effective means for predicting an individual's future level of malaise is to track his/her previous experiences with that stimulus. In summary, effective tools exist for identifying participants at risk for dropout and experiencing intense malaise. With these tools, effective strategies can be devised for mitigating dropout risk and severity of side-effects when used in conjunction with empirically validated exposure protocols proven to reduce maladies.



## VE System Use and Design Guidelines

Overall, the results from this study are in line with what it is expected based on the DPT of neural plasticity (Groves & Thompson, 1970). The DPT suggests that by lowering stimulus intensity the depression opponent process is able to exert greater control over the net outcome than the sensitization opponent process. In this case stimulus intensity was lowered via incrementing drum velocity as well as exposure duration for the H and IH regimens. This created a situation where participants in the incremented regimens experienced a stimulus intensity lower than their non-incremented counterparts and led to the general profile of lower SSQTS, greater postural stability, lower dropout rates, and a greater percentage of overall duration completed compared to non-incremented participants. These results and findings from previous studies that applied various motion sickness mitigation protocols to a variety of provocative environments can be fused together to begin development of guidelines for minimizing malaise, dropout rates, and other adverse negative aftereffects associated with VE use.

The guidelines set forth below are an initial step in directing research and policy for safe and effective VE usage. These guidelines are intended for both VE users and operators as an educational tool and for developing usage protocols. Fortunately, a similar set of guidelines exists for simulator usage (Kennedy et al., 1987) that can be readily updated and applied to VEs as well as guidelines for VE usage under development by Stanney, Kennedy, and Kingdon (In press). The focus of the guidelines set forth here is on empirically validated means of reducing stimulus intensity in VEs, the importance of determining susceptibility and methods for doing so, state of fitness,



exposure duration and intersession intervals (e.g. training curriculum), and finally the effect of level of interaction on side-effects and negative aftereffects.

### Synopsis of Guidelines

Based on the information presented in this document and the findings of this study, a condensed list of VE usage guidelines, followed by design guidelines, is provided below. It should be noted that additional VE usage guidelines can be found in Stanney, Kennedy, & Kingdon (In press) and supplementary design guidelines can be found in Kennedy et al (1987). These guidelines are meant to add to the aforementioned guidelines and minimize recapitulation of existing ones.

#### VE Usage: Pre-exposure

- Utilize the MHQ and scoring key developed by Kennedy et al. (In press) to identify moderate to high susceptibility individuals.
- Assess an individual's state of fitness, if he/she reports not being in his/her usual state of fitness, suggest he/she postpone exposure. If the individual reports being in his/her usual state of fitness, have him/her complete a pre-exposure SSQ. SSQ total scores ranging from 0 to 7.48 are negligible, scores of 11.22 and 14.96 are acceptable, but the individual should be monitored closer than usual; scores greater than 14.96 are unacceptable and the individual should be asked to postpone exposure.



- Assess pre-exposure postural stability and hand-eye coordination to serve as benchmarks for determining when an individual is safe to leave the facility on his/her own accord.
- Educate the individual on the signs and symptoms of VE related side-effects as well as their time course.
- Create an exposure regimen that is tailored to the individual's susceptibility and state of well being that day. Consider an incremental or repeated exposures approach for moderate to highly susceptible individuals as well as individuals with moderately high pre-exposure SSQ total scores.
- Determine appropriate exposure duration based on susceptibility. High susceptibility individuals should have brief initial exposures no longer than 15 minutes, be encouraged to prematurely withdraw from their exposure at the onset of symptoms, and exposure duration should not be lengthened until the individual is able to complete the current duration with minimal inflation of SSQ total score (e.g. an increase in score no greater than 11.22 to 14.96). Low susceptibility individuals should start with longer exposure durations (e.g. 30 minutes) and be encouraged to remain in the VE if symptoms do not escalate beyond mild to allow adaptation.
- Determine intersession interval for repeated exposures keeping it within the 2 to 7 day range. If repeated exposures within a session are necessary, then they should be spaced at least 2 hours apart, but are not recommended.



### VE Usage: During Exposure

- Monitor the individual for obvious signs of malaise including sweating, pallor, burping, drowsiness, dizziness, and emesis.
- To track well-being during exposure, infrequently (e.g. every 10-15 minutes) administer a condensed (i.e. only the scored items) verbal version of the SSQ if it does not interfere with the task at hand. Caution should be exercised in doing this to keep from potentially hypersensitizing an individual to symptoms they may not be experiencing. If the individual reaches a pre-determined tolerance limit for SSQ total score before dropping out, remove them from the virtual environment.
- Upon onset of symptoms, limit intense or rapid movements (e.g. minimize movements in the roll axis or actions such as rapidly turning a corner).

### VE Usage: Post Exposure

- Administer the SSQ, postural stability tests, and hand-eye coordination tests immediately upon exiting the virtual environment. Continue administering these tests until an acceptable deviation from pre-exposure benchmarks has been reached.
- Provide individuals with real world analogues of the tasks completed in the VE to hasten reacclimation of postural stability and hand-eye coordination.
- Keep file of post-exposure SSQ scores over repeated exposures to track the effectiveness of the exposure regimen and further assess an individual's susceptibility and rate of adaptation.



## Design Guidelines

These guidelines focus solely on methods for minimizing stimulus intensity in an effort to mitigate side-effects and are based on the discussion in the future research section.

- **Field of View (FOV):** Tasks that are not hindered by a reduction in FOV should consider minimizing FOV in initial exposures and gradually expanding it across subsequent exposures or later in the exposure duration. The extent to which FOV is minimized will be driven by practicality, user acceptance, and task requirements.
- **Scene Content:** Simplifying scene content is a risky, yet effective, method of mitigating side-effects that should be done based on the task being trained. For dynamic VEs where an individual is moving through a VE or when the VE is moving around them, motion parallax and optic flow can be compromised if heading and steering are of minimal importance in the task. Optic expansion and binocular motion can be compromised if collision detection is of little importance. The reader is urged to consult Wann and Mon-Williams (1996) for an in-depth discussion of this topic.
- **Axes of Control:** Initial exposures should begin with partial control that allows translational movements (i.e. up/down, side-to-side, front/back) and limited rotational movements when necessary (i.e. yaw and pitch, but not roll); head tracking should be deactivated. The next increment in intensity would be to activate full control that allows for translational and rotational movements, including roll. It is debatable if head tracking should be activated at this point or



not. The final increment would be to activate head tracking as well as complete translational and rotational freedom. These increments can be done within an exposure or across repeated exposures.



## CONCLUSION

In brief, this study demonstrated that incremental and repeated exposure regimens are effective for mitigating visually induced motion sickness and dropout rates. In addition, the results showed that the MHQ is a powerful tool for classifying motion sickness susceptibility. Lastly, it was shown that gender differences in visually induced motion sickness may not be as prominent as originally thought when susceptibility is balanced among the genders.

The incremental regimens, despite not always being statistically different than their non-incremented counterparts, were consistently more effective in mitigating side-effects as measured by the simulator sickness questionnaire. This was particularly true when analyses were performed looking at regimen by susceptibility. These analyses showed that among the high susceptible participants, the incremented regimens continually had lower SSQ total scores across all sampling periods. The same pattern held true for dropout rates in the A and IA conditions. Six of the seven dropouts in the A and IA conditions were high susceptibles, but only two of them were in the incremental adaptation regimen. Perplexingly, the same pattern for dropouts did not apply to the H and IH regimens, but percent of overall exposure duration completed for both regimens was above 90%. The implications of these findings is that regimens tailored to an individual's motion sickness susceptibility can be effective in mitigating malaise and dropout rates, while extending exposure durations.



The application of the MHQ scored using a key for sickness induced by optokinetic stimuli proved effective in denoting high and low susceptibles and subsequently identifying those at risk for experiencing intense malaise and dropout. This finding is important because it allows supervisors designing exposure protocols to identify at-risk individuals prior to exposure who may benefit from incremented and repeated exposures regimens based on a query of only two sample questions. Furthermore, the effectiveness of utilizing post exposure SSQ total scores to predict future probability of malaise for an individual may help in fine tuning an individual's exposure protocol and assessing that individual's rate of acclimation.

In regards to gender, the lack of differences between males and females among the dependent variables of this study suggests that gender differences may not be as large as previously thought. Equally distributing susceptibility among the genders effectively abated gender differences, which have been consistently reported in motion sickness research. This is important because it allows equal opportunity for VE usage among the genders and negates the need for designing exposure protocols centered around gender, which instead can be focused on susceptibility.

Results from this study also suggest that using incremental regimens may result in immediate post-exposure sickness scores 25% lower in single prolonged exposures and 20% lower in repeated exposures compared to non-incremental regimens. Furthermore, single exposure dropout rates among high susceptibility individuals using incremental regimens may be reduced to 40% compared to 80% in non-incremented regimens. In regard to percent of overall exposure duration completed in single exposures, incremental approaches may yield values as high as 90% compared to 75% in non-incremented



approaches. Finally, these findings suggest that moderate to high susceptibility individuals utilizing incremented protocols in single and repeated exposures can anticipate consistently less intense malaise, lower dropout rates, greater percentage of exposure duration completed, and greater postural stability post-exposure than their non-incremented counterparts.



## FUTURE RESEARCH

The findings from this study have opened new lines of research to further enhance the knowledge base for effective cybersickness management through exposure regimens. One of the areas in which future research would be beneficial involves methods for reducing stimulus intensity in a virtual environment. There are several options for reducing stimulus intensity in a VE, depending upon what the VE is being used for. One of the first options is to minimize the field of view (FOV) to a level that does not affect task performance and gradually open it up over time and/or exposure sessions. An alternative means to minimizing FOV, without physically restricting it, which retains effectiveness, is to have the user fixate on a point (e.g. a gun sight) in the center of the display (Stern et al., 1990). The reason for minimizing FOV is that it is believed to be one of the factors that drives vection. It has been accepted that large FOV optical flow patterns characteristic of self-motion covering a substantial portion of the peripheral retina are effective in producing vection (Dichigans & Brandt, 1978; Hettinger & Riccio, 1992; McCauley & Sharkey, 1992; Kennedy et al. 1998; Van Cott, 1990); Andersen and Braunstein's (1985) findings are an exception to this generality. Therefore, by reducing FOV or fixating on a target, one is able to reduce the sensation of vection. Vection by itself it is capable of producing side-effects (Dichigans & Brandt, 1978; Crampton, & Young, 1953) and may be an important element in simulator and cybersickness (Hettinger et al., 1990; Kennedy & Fowlkes, 1992; Hettinger & Riccio, 1992; Kennedy,



1996; Smart, Hettinger, & Stoffregen, 1999, So & Lo, 1999). DiZio and Lackner's (1997) findings demonstrate the utility of reducing the FOV to mitigate side-effects in VEs. They used a HMD based VE that had a full FOV of 126 degrees wide by 74 degrees high. They found that by halving the linear dimensions of the FOV, intensity of side-effects were also halved. However, it is unclear if the reduction of FOV led to the reduction of sickness or whether the refresh rate of the visual scene content was improved by minimizing scene content. Regardless, DiZio and Lackner have shown that reducing FOV can be an effective means to minimizing cybersickness, while Westra (1983), Westra and Lintern (1985), and Westra et al. (1986, 1987), have shown that performance benefits gained by a wide FOV are task dependent. Clearly, manipulating FOV may be an approach to reducing the provocative nature of some VEs in which a large FOV is not essential for the task being trained and, therefore, should be pursued empirically.

Another method of reducing stimulus intensity is to manipulate the scene content, in particular factors that drive vection. Candidate items for future research include spatial frequency (texture density), stationary elements in the background and foreground, flow velocity of optical imagery (edge rate), and global visual flow. Unfortunately, reducing scene content in a VE may affect task performance. For example, Warren and Hannon (1998) and Wann, Rushton, and Lee (1995) have shown that reducing the spatial frequency content of the visual scene and degrading optic flow might reduce side-effects, but may also reduce one's ability to detect direction of heading. Furthermore, optic flow has been shown help individuals learn to navigate synthetic environments (Kirschen, Kahana, Sekuler, & Burack, 2000). In addition, removing stereoscopic depth cues to mitigate side-effects may lead to a decrement in collision avoidance (Heuer, 1993; Wann,



1996, Wann & Rushton, 1995). In essence, the visual cues capable of producing side-effects are also essential for precise control (Wann & Mon-Williams, 1996). However, with well-grounded research there may be means to mitigate side effects while preserving the benefits provided by rich scene content.

The final means of reducing the cybersick-provoking intensity of a VE presented herein is to restrict axes of movement. Axes of movement refers to the axes in which the user is able to translate (vertical and horizontal) and rotate (yaw, roll, and pitch) during locomotion in the VE, and the activation of head tracking while exploring the visual scene (e.g. no head tracking vs. 6 degree-of-freedom (DOF) head tracking). Only two studies (Rich & Braun, 1996; Stanney & Hash, 1998) have been found in this literature review that deliberately manipulated axes of control to investigate its effect on cybersickness. In their write-up, Rich and Braun (1996) suggest that their findings may have been confounded and, thus, are not reviewed here; however, the findings of Stanney and Hash (1998) are. Stanney and Hash (1998) performed a study that looked at the effect of axes of navigational control on adaptation; all participants had head tracking. They examined three conditions: 1) active (provided a joystick to maneuver forward & backward, side to side, up & down, roll, pitch, and yaw), 2) active-passive (provided a joystick to predominantly move forward & backward, side to side, up & down, and in specific circumstances yaw and pitch), 3) passive (passively observed scripted movements). The interesting portion of their findings is that the active group experienced more cybersickness than the active-passive group. These results may indicate that rotational movements in a VE are a more intense stimulus for cybersickness than translational movements.



Reason and Benson (1978) performed a study looking at the effect of passive, active-passive, and active control in combination with incremental adaptation. They used rate of neutralization and the magnitude of the oculogyral illusion (OGI) as their measure of adaptation and found that the active-passive condition yielded better adaptive efficiency in regard to the rate of OGI neutralization and diminished the magnitude of the OGI at each stepwise increase.

The number of studies investigating the effects of head tracking vs. no head tracking on cybersickness has also been scant. However, it has been noted through anecdotal evidence (Cobb et al., 1999; Kennedy et al., 1987; Howarth & Finch, 1999; Kennedy & Fowlkes, 1992) and a few empirical studies (Finch & Howarth, 1996; Rich & Braun, 1996) that conditions with head tracking were more nauseogenic than without head tracking. It has also been found that cybersickness may result solely from head movements in a VE with a stationary visual scene (DiZio & Lackner, 1997).

Based on these studies it is suggested that research into incrementing degrees of freedom of control, both movement and head tracking, after acclimation to translational movements has occurred, may provide another effective means to mitigating cybersickness. The aforementioned studies support this line of research and have demonstrated that providing the participant partial (active-passive) control rather than full (active) control may yield more rapid acclimation to the altered sensory environment, thus yielding more complete acclimation before progressing to a higher intensity stimulus.

Another important vein for future research includes methods for determining motion sickness susceptibility. This line of research began in simulators in the mid 1960s



with the work of Kennedy and Graybiel (1965) developing the MHQ. Shortly after, a variant of the MHQ was developed by Reason and Brand (1975) that essentially asked the same questions as the MHQ in a different format and used a different scoring procedure. The MHQ has been keyed and proven effective for various types of motion sickness provoking environments including simulators (Kennedy, Fowlkes, Berbaum, & Lilienthal, 1992) and recently VEs (Kennedy, Lane, Grizzard Stanney, Kingdon, Lanham, & Harm, In press). The importance of utilizing the MHQ and applying an appropriate scoring key for VEs is immense. Of most relevance is the ability to predetermine individuals who are likely to experience intense malaise and/or dropout, particularly with increased use of VEs for training purposes. Kennedy et al. (In press) suggest that 25% to 50% of the training population may not be able to withstand VE induced side-effects, which highlights the need to for continued research on methods for identifying highly susceptible individuals. Kennedy et al. (In press) note that utilizing the MHQ is an effective way of regulating cybersickness and with continued research and development false positive rates could be as low as 5-10% while correct identifications could be 50% or higher. Furthermore, the MHQ may benefit from a retooling of the questions to replace those that were appropriate for the time frame of its genesis with questions abreast with today's common provocative motion challenges and various populations of VE users.

Continued research into the effects of exposure duration is also warranted. While it has been shown that exposure duration has a cumulative effect on sickness (Kennedy, Stanney, & Dunlap, In press), research into manipulating exposure may be one of the best ways to control severity or incidence of cybersickness (Kennedy et al, 1996; Kennedy,



1996). In addition, research into manipulation of exposure durations may have large payoffs because it has been estimated that 20-50% of the variance in cybersickness can be accounted for by the amount of time a person spends in a VE and the ISI (Kennedy, Stanney, & Dunlap, 2000). Particular areas of research to focus on are the effects of prolonged exposures (e.g. 2hrs) to investigate its effect on negative aftereffects and how long it takes individuals of varying susceptibility to complete the adaptive process. It would also be beneficial to study the effect of self-regulated exposure durations (e.g. participant withdraws at the onset of mild to moderate symptoms) on acclimation in a repeated exposure regimen based on the work of Hu and Hui (1997).

The last area of future research discussed here is the effect of negative aftereffects and methods to rapid reacclimation. Negative aftereffects are traditionally comprised of all symptomatology occurring post stimulus exposure, which in VEs includes, but is not limited to, malaise, sopite syndrome, postural instabilities, and changes in hand-eye coordination. The negative aftereffects of concern here are the more insidious of the group, postural instability and shifts in hand-eye coordination. These two negative aftereffects are focused on here because they are harder to detect than overt sickness and sopite syndrome; they may be present when malaise and sopite are not, and they have the potential for putting individuals at risk. Empirical findings have demonstrated the potential for postural instabilities and shifts in hand-eye coordination to occur as a result of VE and simulator exposure (Stanney, Kennedy, Drexler, & Harm, 1999; Stanney, Salvendy, et al., 1998; Cobb, 1999; Kennedy & Stanney, 1996; Kennedy, Berbaum, & Lilienthal, 1997; Kennedy, Drexler, & Compton, 1997), but their detection may depend on measurement techniques (Cobb, 1999). The positive side of these empirical findings is



that, in general, the postural instabilities and changes in hand-eye coordination arising from VE and simulator use are short lived (Cobb, 1999; DiZio & Lackner, 1997) when exposure durations are limited (e.g. 30 minutes or less). However, as effective means of prolonging exposure durations are developed that afford adaptation of the individual's hand-eye and postural coordination to the altered sensory environment (i.e. VE) the problem of negative aftereffects are likely to increase. For example, McGonigle and Flook (1978) found significant negative aftereffects in individuals two to four weeks after completing a repeated exposure regimen for prism adaptation. Furthermore, Guedry (1965) demonstrated long lasting changes in the vestibulo-ocular reflex that persisted up to 60-90 days following a 12-day exposure to a slow rotation room. The relevance of these findings is that as progress is made in methods for acclimating individuals to VEs for combating side-effects during exposure, the risk of negative aftereffects increases, particularly with protracted and repeated exposure durations. Fortunately, individuals scheduled for frequent repeated exposures may benefit if effective dual adaptation regimens can be established.

In summary, the potential for negative aftereffects exists, and it is important that research into sensitive measures of postural instabilities and shifts in hand-eye coordination continues. Furthermore, the development of dual adaptation regimens should be pursued that consist of generic readaptation task batteries applicable to a wide range of virtual environments. Ironically, as VE technology and methods for adapting progresses, the need for this research heightens as the tasks being trained within the VE are the ones most likely to be affected post exposure, particularly those involving fine motor control.



## APPENDIX



The MHQ scoring key used in this experiment was developed by Graeber (In Press) for determining susceptibility to circularvection in an optokinetic drum. Presented below are the items in the key and how each question was scored in parentheses. Total score is the sum of the answers to the questions. A total score less than or equal to 2 was deemed low susceptibility and a score greater than 2 was deemed high susceptibility.

- If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?
  - Almost certainly would (3), Probably would (2), Almost probably would not (1), Certainly would not (0)
- In general, how susceptible to motion sickness are you?
  - Extremely (4), Very (3), Moderately (2), Minimally (1), Not at all (0)
- The following questions are Yes (1) / No (0) questions.
  - Do you experience stomach awareness in cars?
  - Do you experience stomach awareness on long train/bus rides?
  - Do you experience headaches on roller coasters?
  - Do you experience dizziness when watching movies at theaters?



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