DETERMINING MOTION CUING REQUIREMENTS FOR THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV) DRIVER SIMULATOR

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ABSTRACT

A determination was needed regarding whether or not to incorporate a motion base into the future Marine Corps Advanced Amphibious Assault Vehicle (AAAV) Driver Trainer, and if so, the degrees of freedom (DOF) required to produce an accurate simulation. A force motion base was proposed as an option in the Naval Air Warfare Center Training Systems Division (NAWCTSD) AAAV Front End Analyses and in an industry-generated Systems Functional Specification, however, rationale for the necessity of force motion was not available. The task of determining the necessity for force motion cuing and the DOF required was somewhat formidable because no actual operational vehicle presently exists and only limited models of the vehicle and the environments in which the vehicle will operate are currently available. The end decision to incorporate platform motion into the AAAV Driver Trainers was based on data supplied from a number of sources (e.g., training effectiveness and cost data, historical data such as the Army's experience with the M1/A1 tank, and subject matter expertise). As part of the decision process, it was necessary to use analytic methods to determine the DOF that would be required to meet AAAV driver training objectives.

A survey was developed by the Training Technology Development Branch at NAWCTSD to query members of the AAAV Fleet Project Team regarding the expected salience of motion cues in each of six DOF (i.e., longitudinal, lateral, vertical, roll, pitch, yaw) for specified tasks and environmental conditions. Five enlisted Marines, with considerable experience driving the predecessor Amphibious Assault Vehicle (AAV-7A1), used a 6-point Likert-type scale to rate the intensity of expected motion forces for each of 22 anticipated AAAV training tasks to be performed in both water (sea state 1) and land operations (various surfaces). Survey results indicated that motion forces are expected to be greatest in the longitudinal, vertical, pitch and yaw axes during performance of the specified tasks. A set of decision heuristics, developed for the U.S. Army by Sticha, Singer, Blacksten, Morrison, and Cross (1990), was applied to the survey results to formulate recommendations for motion cuing requirements. The methods used to determine motion requirements for the AAAV Driver Simulator can be applied to any ground vehicle or waterborne craft, and similar results can be expected. The results of the research conducted were not the only factors considered in determining the requirement for motion, but helped to reinforce many assumptions about the need for motion cuing.

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INTRODUCTION

Purpose. Front-end analyses conducted by the Naval Air Warfare Center Training Systems Division (NAWCTSD, 1998) indicate that a full mission simulator would be beneficial for Advanced Amphibious Assault Vehicle (AAAV) driver training. In the absence of rationale for motion cuing requirements, cost options were proposed both with and without a motion base. A determination was needed regarding whether to incorporate a motion cuing platform into evolving functional specifications for the training device. The task of determining the extent of force motion cuing required for effective driver training was formidable because no actual vehicle currently exists and only limited models of the vehicle and the environments in which the vehicle will operate are available. Rationale was needed to support trainer design decisions at this early stage of the driver training system requirements definition process.

The objective of the present analysis was to document rationale to support a motion cuing decision for AAAV driver training. A second objective was to infer the salience or 'hoticeability'' of motion cues in each axis of AAAV motion for specific tasks in specific operating environments based on predecessor AAV-7A1 experience and knowledge of planned AAAV dynamics.

Organization. The AAAV mission, design, and operating requirements are introduced first. Included are planned instructional objectives for the driver trainer, to draw attention to relevant issues that were brought to bear in formulating a motion cue decision.

A brief overview on human motion detection senses is provided next. Common methods for imparting simulated inertial cues are described with particular emphasis on visual and vestibular stimulation. Trends in motion cuing hardware are reviewed, followed by a historical synopsis of the U.S. Army's

experiences with motion cuing technologies for tracked ground vehicle simulation.

An assessment of the debate over the training effectiveness of motion cuing platforms is presented next, followed by a summary of arguments for and against the use of platform motions. The decision heuristics developed by Sticha, Singer, Blacksten, Morrison, and Cross (1990) are introduced to provide a basis for integrating the results of the motion survey reported here into motion/no motion decisions.

The Method section describes the motion survey and procedure used to estimate the salience of motion cues anticipated in each of six degrees of freedom (DOF) for 22 AAAV driving tasks performed under specified conditions. The Results section summarizes the survey findings. The Discussion provides a synopsis of the rationale for a motion system to accommodate the training tasks that may benefit from motion cuing as indicated by the survey results and additional considerations.

ADVANCED AMPHIBIOUS ASSAULT VEHICLE

Mission. The AAAV will play a critical role in twenty-first century Marine Corps tactics to forward deploy troops and equipment from sea to land objectives. The evolving doctrine of over-the-horizon assault is the result of a modernization of war fighting tactics to take full advantage of the littoral (coastline) environment and the maneuvering space it provides. According to the U.S. Marine Corps <u>Concepts and Issues 1998</u>, 'Revitalizing the necessary platforms and improving the effectiveness of these expeditionary forces is a major goal'' (USMC, 1998, p. 48). The AAAV will replace the current AAV-7A1 family of amphibious assault vehicles, which will be more than 30 years old by the time the AAAV is fielded. A top-level description is provided next: Specific details were consciously omitted.

Vehicle Design. The AAAV will use the most power-dense diesel engine in the world and will be the first U.S. combat vehicle to use fully retractable hydro-pneumatic suspension units, which will provide land mobility equivalent to, or better than, the Army's M1A1 battle tank (DoN, 1998). Two internal waterjets will provide high-water speed propulsion. Improvements over the predecessor AAV-7A1 include increased mobility on land and sea and enhanced survivability due to enhanced firepower, armor, and Nuclear, Biological, and Chemical (NBC) protection.

The net change in cubic space between the AAAV and the AAV-7A1 will be minimal, however, the AAAV will weigh substantially more than its predecessor (DoN 1997). Although the many design modifications will change the distribution of weight, the center of gravity of the AAV-7A1 and AAAV are predicted to be roughly the same. Differences in the weight and load distribution can be expected to contribute to differences in the handling characteristics between the two vehicles, and variations in AAAV weight as a function of payload (e.g., fuel load, ammunition, onboard equipment material and troops), will effect AAAV handling characteristics across missions.

Operating Requirements. The AAAV will maneuver aboard amphibious shipping for transportation, launch, and recovery and will have the ability to rapidly transition from sea to land operations. The majority of AAAV operations will occur on land, and a lesser percentage will occur in ocean and riverine environments. High water speed will be achieved at sea by retracting the vehicle's suspension and deploying appendages to create a large planing surface. According to Feigley, Beagles, and Daly (1990), the dynamics of the AAAV on-plane will be similar to that of an airplane, and, 'the interaction of speed, wind, current, waves, and sea spray will push the capabilities of the driver and crew'' (p. 476).

The AAAV is expected to survive in high sea states and shall be capable of righting itself from rolling in rough sea conditions. On land, the AAAV must be capable of crossing trenches and conducting extended riverine operations including executing hasty river crossings and traversing saturated riverbanks. The AAAV must negotiate slopes in forward and reverse gears and side slopes in either direction in both empty and fully combat-loaded conditions, and, will be capable of climbing a 3-ft vertical wall from a standing start.

Driver Interface. AAAV acceleration, deceleration and heading will be controlled via throttle, brake, and steering yoke inputs, respectively. With the exception of the velocity indicators and perhaps RPM, most of the instrument displays and gauges are of little consequence, if any, to the present analysis. Unlike an aircraft, there are no instruments such as attitude indicators to verify vehicle orientation.

The AAAV driver's forward out-the-window view will consist of five windows ('vision blocks'), separated by partitions, for a combined field-of-view (FOV) of about 120 deg horizontal (h) x 30 deg vertical (v), that is offset to one side of the vehicle. A thermal viewer is being considered that would provide an even narrower 'periscope-type" view to be used during high water speed as the bow plane obscures the driver's view when the vehicle is 'on-plane" (operating at high water speeds). As currently designed, there are no provisions for driver vision to the rear of the vehicle and the driver's forward view of the outside environment will be restricted in normal operations and very restricted during adverse conditions and during high water speeds.

AAAV Driver Training System Objectives. The driver simulator will be used to train operators on: (1) the operations of the driver's crew station; (2) communications procedures; (3) driving techniques for various sea and land conditions (including transition surf zones and high speed driving while maintaining appropriate formations); (4) techniques for embarkation and debarkation for amphibious operations during various sea states and day or night visibility; and, (5) emergency procedures for various system malfunctions during land and sea operations (NAWCTSD, 1998).

Driver Training System Students. The AAAV Driver Simulator is being developed to train novice students at the AAAV schoolhouse. These students will be assigned to the AAAV schoolhouse directly from basic training. They will have no experience driving the AAAV or any other military tactical track vehicles. In addition to the Driver Simulators, students at the schoolhouse and in the fleet will learn and improve their driving skills through a combination of actual vehicle operation and embedded training capabilities being incorporated into the AAAV.

In addition to training system functional definition, a motion/no motion decision was required early on, to determine schoolhouse facility requirements. The remainder of the paper documents the rationale used to support the motion/no motion decision.

SELF-MOTION MOTION DETECTION

The primary sensory mechanisms for self-motion detection consist of the eyes, vestibular organs, tactile receptors, and the proprioceptive and kinesthetic senses. Whereas visual stimulation provides velocity and position cues, vestibular stimulation yields acceleration cues resulting from forces and rates of onset acceleration resulting from changes in force (Matheny, Lowes, & Bynum, 1971). Humans tend to detect vestibular cues of acceleration approximately 160 msec before inertial effects are sensed through vision (Albery & Kron, 1978).

The tactile, proprioceptive, and kinesthetic senses, consisting of the skin, muscles, tendons and joints, also detect cues of initial acceleration, called "onset cues." The proprioceptive and kinesthetic senses signal the relative position of body parts and their movements based on biomechanical reactions of the head and limbs. The tactile receptors are primarily pressure sensors that respond to motion stimuli faster than the eyes and may be even more responsive than the vestibular sensors (i.e., semicircular canals and otoliths; Albery & Kron, 1978). Due to rapid rates of onset, vestibular and tactile stimulation are ideal for providing cues of maneuvering motion and external forces ("disturbance motion"), and may render the first warning of impending crises.

MOTION CUE GENERATION OVERVIEW

Out-the-window visual displays and motion platforms are the primary means of imparting motion cues to simulator trainees. Secondary means of generating motion cues include instrument displays, auditory cuing systems and force feedback via control loading systems (Mooij, 1987). Whereas simulator visual displays impart optical indicants of self-motion, motion cuing systems such as motion platforms, g-seats and seat shakers provide mechanically induced motion cues that stimulate the vestibular, proprioceptive, tactile, and kinesthetic senses. The present analysis focuses on the relative contributions of the more dominant visual and platform motion cuing systems and relative implications for AAAV driver training.

Visually-Induced Motion Cues. Sustained visual scene motion can induce illusory sensations of self-motion known as ‘‘vection.’’ Vection is an optical illusion that makes you feel like you’re moving when you’re really not (or at least not to the extent that is visually implied). Movie theaters and amusement parks capitalize upon the vection phenomenon to induce compelling sensations of illusory self-movement in relatively stationary observers. Common examples include wide-screen movie cineramas such as the EPCOT’s Circle Vision 360-degree “Wonders of China’’ motion picture exhibit or the IMAX theater at NASA’s Kennedy Space Center. Platform motion can be used to enhance vection sensations, and theme park rides such as Universal Studios’ ‘Back to the Future,'' and EPCOT Center's 'Star Tours'' and 'Body Wars'' attractions take advantage of this effect.

Vection experiences are mediated by the motion detection capabilities of the peripheral retina (as opposed to the high-acuity central, or foveal, portion of the retina). During locomotion, the point toward which one is moving appears fixed and the entire visual field appears to radiate from that point (Gibson 1966). This streaming of scene details creates optical flow patterns that are sensed by the peripheral vision system and interpreted as self-motion. The level and type of scene detail has direct implications for the observers' perception of self-motion and, by implication, the control and execution of tactical maneuvers. Simulator manufacturers have long relied upon these principles to impart sensations of vehicular movement. Inadequate stimulation of the peripheral visual system will not likely elicit the desired motion perception effect. As such, force motion cuing technologies may be required to provide effective vehicular control training, and are addressed next.

Mechanically-Induced Motion Cues. Motion cuing systems have long been used in flight simulators to provide indications of acceleration, vibrations, and turbulence disturbances in support of visual sensations (Mooij, 1987). There are several different types of systems available to simulate motion cues including seat shakers, g-seats, and motion platforms of varying complexity. Seat Shakers enhance sensations of movement provided by visual displays and motion bases, but do little beyond providing cues that indicate engine speed and terrain quality. G-seats provide controlled pressure redistributions across the seat surface to simulate sustained gravitational forces. Seat shakers and motion platforms (individually or in concert) are commonly used to simulate inertial forces in aviation and ground vehicle simulators, while g-seats are used almost exclusively in high-performance jet aircraft simulators.

Whereas a g-seat, g-suit, or stick shaker can be used to provide onset cues to the tactile, proprioceptive, and kinesthetic senses, these cuing mechanisms provide little, if any, vestibular stimulation by virtue of their lack of displacement called 'excursion'' (Butrimas, 1981). Also, of importance to the present analysis, the output of the tactile (also known as somatosensory) receptors returns to a baseline level during sustained uniform application of pressure, as would occur with a g-seat or g-suit (Mooij, 1987). Due to the inherent limitations of g-seat technologies, the present analysis focused only on the potential training utility of incorporating a motion platform into the AAAV driver simulator.

Motion platforms indicate onset cues as well as prolonged accelerations. Onset cues are imparted via high frequency platform motion, whereas long term accelerations are generated by very low-frequency platform motion in the tilt axes (Mooij, 1987). The dynamic response range of a simulator motion system can be specified in terms of the number of axes or DOF, and, for each DOF, the maximum frequencies, amplitudes, accelerations, and the washout rate (Sticha et al., 1990). Motion platforms can simulate forces in up to 6 DOF: Pitch, roll, yaw, and longitudinal (surge), lateral (sway) and vertical (heave) acceleration. Depending on the tasks to be trained in the simulator, any combination of axes can be used to obtain desired results.

Motion base technology has recently progressed from large, expensive, high maintenance hydraulic systems to smaller, less expensive, cleaner, and more economical electro-mechanical systems. Even more recently, an electro-magnetic motion base has been prototyped that may provide greater bandwidth and energy efficiency over the current electro-mechanical bases.

Motion Bases in Tracked Vehicle Driver Trainers. The U.S. Congress recognized a need for tracked vehicle simulation by the late 1970's, forced in part by escalating fuel prices and environmental concerns raised both in the U.S. and by our allies abroad. According to Reese (1991), the U.S. Army's initial attempt to develop an

M1 Tank Driver Trainer was ''doomed to failure since the trainer did not provide interactive visual or motion cuing to the student'' (p. 148). Army engineers then turned to Britain and France to provide data to create minimal technical requirements for tracked vehicle simulation since European armies had successfully used simulators to train their tracked vehicle drivers since the early 1970's (Reese, 1991). Unfortunately, there was a lack of documented rationale for technical fidelity issues such as minimal levels of visual, motion, tactile (e.g., control loading), and dynamics fidelity required to impart effective driver training.

Although early European tank simulators were technology-limited to 2-DOF hydraulic motion cuing platforms (pitch and roll), 3-DOF systems (pitch, roll and yaw) became the industry standard by 1980 (Reese, 1991). Following the European lead, U.S. Army engineers specified 3-DOF motion base technology (pitch, roll, and yaw) when purchasing simulators for the M60 tank driver trainers (the visual system used existing terrain model board technology). Concurrently, the Army initiated a research and development program to produce a driver simulator for the M1 Main Battle Tank that fortuitously took advantage of evolving 6 DOF motion base technology.

Reese (1991) summarized the U.S. Army's experiences in seeking rationale for motion cuing requirements in the M1 and M60 tank driver trainers as follows:

> ''There are many who believe that motion is not required. In 1985, the United States Government hoped that the Europeans had developed empirical data for determining the necessity for motion cuing. Unfortunately, the data does not exist. In fact, the German Army recently visited the United States hoping that the Army had developed the same empirical data for the M1 tank driver trainer. Unfortunately, we have not. Such a test is expensive and lengthy. The Government engineering team, however, firmly believes that motion cuing for ground based training is critical, especially for beginning level students. The M1 and M60 trainers were, in fact, created primarily for beginning level students. Training tasks such as wall, log, and ditch crossings require some type of motion cuing to be effective. What is not evident is the degree of motion simulation required. While the M60 simulator trains effectively with a three degree–of-freedom motion platform, the M1 device uses a small six degree-of-freedom system. What is the minimum requirement for motion? It is an issue recommended for further research as it represents a significant cost element for driver simulation. The necessity for motion was obvious during the Army's User Test, however, when several students became nauseous when the motion systems were turned off. The physiological interactions and requirements for motion cuing are still little understood'' (p. 152).

Reese's (1991) article provides a historical overview into the rationale that went into the Army's decisions to include platform motion cuing in their tank driver trainers, and anecdotally notes problems with simulator sickness when the motion system was turned off. Reese did not describe the methods by which both motion platforms were determined to provide adequate inertial cuing. In fact, the training effectiveness value of motion cuing platforms has been a source of major debate in the training and simulation literature regarding the need for motion base enhancements to training devices with high fidelity, vection-inducing visual systems.

TRAINING EFFECTIVENESS ISSUES

Boldovici (1992) reviewed transfer-of-training research that examined performance in parent vehicles as a function of simulator training, with or without platform motion, but was unable to find any results that demonstrated that motion cuing resulted in superior transfer to fixed- or rotary-wing aircraft, or to ground vehicles. Jacobs, Prince, Hays, and Salas (1990) reached similar conclusions in a meta-analysis of flight simulator training research:

> 'For jet training, motion cuing was found to add nothing to the simulator training effectiveness, and in some cases, may have taken away from the training value of the simulator. However, this finding may not be truly representative of the effectiveness of motion-based training since: 1) there was a lack of periodic calibration of the motion cuing systems; and 2) the results were based on all tasks combined. The positive effect of motion for any one task may have been masked by the negative effects of motion for another task'' (pp. 8-9).

Boldovici (1992) reminds us that, 'Results that show no difference between the effects of motion and no motion on transfer to parent vehicles do not prove that no differences exist'' (p. 22). Rather, the lack of differences in transfer performance may be due to factors unrelated to motion such as insufficient statistical power and other experimental deficiencies. As such, there is little hard evidence to determine whether motion bases are beneficial to training or not.

In the absence of supporting transfer of training data to support selection of motion cuing options, Boldovici (1992) compiled rationale for and against the use of force motion cuing based on correspondence with 24 subject matter experts (See Table 1). Boldovici (1992) contends that the inabilitity to practice some tasks without physical motion cues is a good justification for buying a motion base. Cues that set the occasion for responses and increase their probability, called 'discriminative stimuli,'' can be analyzed to identify which tasks require motion in order to be practiced.

Arguments In Favor Of Using Motion
A theorized reduction of the incidence of simulator sickness
Relatively low cost compared to other simulator features (e.g., visual displays)
Users' and buyers' acceptance is increased
Increased trainee motivation
Learning to perform time-constrained, dangerous tasks
Motion as a distraction to be overcome by practice
Application of adaptive or augmenting instructional techniques
Inability to practice some tasks without motion
Arguments Against Using Motion
Absence of supporting training effectiveness research
Achievement of greater transfer by means other than motion cuing that have already been empirically established
Possible learning of unsafe behavior
Undesirable effects of poor synchronization
Direct, indirect, and hidden costs
Alternatives to motion bases for producing motion cuing
Benign force environments that may impart little or no cuing information

Table 1. Arguments For and Against the Use of Platform Motion Cuing Technologies (Compiled by Boldovici (1992).

IDENTIFICATION OF DISCRIMINITIVE STIMULI FOR TASK PERFORMANCE

Analysis Tool. A system using analyses aimed at identifying discriminative stimuli for task performance has been developed by Sticha et al. (1990). This analysis technique employs a rule set for selecting motion cuing technologies that can be applied to aviation or ground vehicle simulators. The rules provide a decision-support system for making trade-offs between training alternatives and allows planners to determine whether any of five means for motion cuing will be required: a g-seat, a seat shaker, a 3-DOF, 5-DOF, or 6-DOF motion base. For each task to be practiced in the simulator, it must be determined if:

- longitudinal acceleration, lateral acceleration, vertical acceleration, yaw, pitch, and roll are moderate or great;
- a motion cue initiates a response to an emergency procedure;
- a visual cue is correlated with motion cues that initiate task performance;
- the task in question is a continuous control task;
- accelerations or decelerations are prolonged over several seconds.

Sticha et al.'s (1990) guidance supports the procurement of a motion platform only if the cues are used to initiate emergency procedures **and** there are moderate to high lateral or yaw accelerations **and/or** there are no correlated visual cues. If a motion base is indicated, the authors provide direction to select the number of DOF required. The present survey sought to estimate the anticipated salience (i.e., noticeability or discriminability) of motion cues in 6-DOF during performance of representative AAAV driver control tasks in support of the analyses recommended by Sticha et al. (1990) to determine the extent of motion cuing required for AAAV driver training.

METHOD

Participants. Five male enlisted Marines, ranging in age from 22-31 years, completed the questionnaire as part of their assigned duties as AAAV Developmental Test Marines (DTM). Team members had an average of 4.6 years of experience driving the predecessor AAV-7A1, with an experience range of 10 to 85 embarkation/debarkation maneuvers from an amphibious ship.

Materials. Each participant received a copy of the questionnaire, a description of the rating scale, and a diagram of acceleration forces in 6-DOF. The questionnaire consisted of a 6-point rating scale (see Table 2), that was used to rate the anticipated salience of motion forces in each of 6 DOF for 22 representative AAAV driver tasks.

An estimated 45 of the 960 driver tasks identified in the AAAV front-end analysis (NAWCTSD, 1998) involve vehicular control, whereby motion forces can be expected. DTM team members participated in reducing the list to a subset of 22 representative tasks involving maneuvering at sea, in the surf zone and on land, to create a more manageable survey. Tasks such as reviewing checklists or switchology tasks were not considered for inclusion in the questionnaire because they are not directly related to vehicular motion.

Rat-ing	Descr-iptor	Behavioral Anchor
0	None	Zero or below perception threshold.
1	Weak	Perceptible, but barely noticeable. Could walk a straight line without side-stepping, no problem
2	Gentle	Could walk a straight line without side-stepping, but would probably have to make postural adjustments.
3	Moderate	Could walk a straight line, but would probably side-step more than once.
4	Strong	Could not walk a straight line.
5	Severe	Would probably fall down.

Table 2. Scale Used to Rate Motion Salience in 6-DOF for 22 Tasks.

Procedure. DTM members participated in three 1-hour sessions of (1) training; (2) the questionnaire; and, (3) a debrief discussion, over two days. Participants were encouraged to ask questions throughout all sessions.

Training Session. The training session was held to familiarize team members with the nature of the questionnaire, rating scale, and the concept of motion in 6-DOF. Instruction on 6-DOF motion was provided using a diagram and through demonstration of hand movements as a metaphor for AAAV motion. All participants practiced moving their hand in 6-DOF until they demonstrated mastery.

Next, each task was discussed to clarify task parameters (e.g., velocity and heading) and environmental conditions (e.g., visibility and terrain quality), to provide a common frame of reference. The rating scale was then discussed and examples were provided.

Questionnaire Session. Team members were asked to demonstrate their knowledge of motion forces in six DOF using their hand as a metaphor for the AAAV, just prior to completing the questionnaire. Team members were instructed to complete the individually, however questions were permitted and were answered aloud to the entire group.

Debrief Session. All ratings were tabulated prior to the debrief session. Any discrepancies of 3-points or more were flagged for discussion. Team members whose ratings differed from those of the others by 3 points were encouraged to explain their rationale. Following discussion, participants were permitted to change their ratings if they so chose, but were not obliged to do so. The discussion suggested that these rating disparities typically resulted from misconceptions regarding the nature of the task or environmental conditions.

RESULTS

Table 3 presents the means ratings of expected motion salience in each of six DOF for the 22 tasks surveyed (standard deviations appear in Italics). To reiterate, a '0'' rating indicated that motion was expected to be nonexistent or imperceptible in a given axis, whereas a '5'' meant that severe motion was anticipated.

Task	LON (x)	LAT (y)	VER (z)	PITC	ROLL	YAW
Debark from static launch	3.4 *.55*	1.6 *.89*	3.6 *.55*	3.8 *.48*	2.0 *1.0*	1.4 *.55*
Debark from underway launch	3.2 *.45*	1.6 *.89*	3.4 *.55*	3.4 *.55*	2.2 *.45*	1.8 *.45*
Perform ready circle	1.0 *.71*	1.4 *.55*	2.0 *.71*	2.0 *1.0*	2.2 *1.1*	2.4 *1.14*
Position vehicle in wave form	2.0 *1.0*	1.8 *.84*	2.0 *1.0*	2.4 *.55*	2.0 *.71*	1.6 *.55*
Night ops driving	2.0 *1.0*	1.6 *.85*	2.2 *.84*	2.0 *1.0*	1.8 *1.1*	2.0 *1.0*
Harbor/ river driving	0.8 *.45*	1.4 *.85*	1.0 *.71*	1.0 *.71*	1.2 *.84*	1.4 *.89*
Driving inbound in surf	3.4 *.55*	2.0 *1.22*	3.8 *.45*	3.2 *.84*	2.4 *.55*	3.0 *1.0*
Negoti-ate 6ft plunging surf	3.2 *.84*	2.6 *.89*	4.0 *.71*	3.6 *1.14*	2.8 *1.30*	3.0 *1.0*
Follow Guide vehicle	1.8 *.84*	2.0 *0.0*	1.8 *.84*	2.0 *1.0*	1.6 *.89*	1.4 *.55*
Conduct basic driving	2.2 *.84*	2.4 *.89*	2.0 *.71*	2.2 *.84*	2.0 *1.0*	2.0 *1.0*
Maintain Course	2.2 *.45*	2.2 *.45*	2.0 *.71*	2.0 *.71*	1.8 *.45*	1.6 *.55*
Decel-erate	1.6 *.55*	1.2 *.84*	1.8 *.84*	1.6 *.89*	1.2 *1.31*	0.8 *.84*
Brake	3.2 *.84*	1.4 *1.14*	2.2 *.84*	2.6 *1.34*	1.6 *1.52*	1.2 *1.10*
Launch from beach	3.0 *.71*	2.4 *.56*	3.2 *.84*	3.0 *1.73*	2.2 *1.10*	3.0 *.71*
Recovery aboard ship	3.0 *1.0*	3.0 *.71*	3.4 *.55*	2.8 .84	2.0 1.0	2.4 .89
Approach to river bank	1.8 .84	1.8 .84	2.0 1.0	1.2 *.45*	1.0 *.71*	1.4 *1.14*
Towing	3.2 *.84*	1.8 *.84*	2.1 *.71*	2,8 *.84*	2.0 *.71*	2.0 *1.0*
Maneuver around obst-acles	1.0 *.71*	1.6 *.89*	2.0 *.71*	1.6 *.55*	2.6 *1.14*	3.0 *.77*
Drive in forma-tion	3.2 *1.1*	1.8 .84	2.4 *1.34*	2.6 *1.52*	1.2 *.84*	2.8 *1.30*
Well Deck Ops	1.8 *1.1*	0.8 *.45*	0.4 .55	1.2 *.84*	0.8 .84	2.0 1.0
Drive on land (flat surface)	2.2 *.84*	0.6 *.55*	0.4 *.55*	0.4 *.55*	0.2 *.44*	0.6 *.55*
Drive on land (rough terrain)	3.4 *.89*	2.2 *.84*	3.0 *1.58*	3.8 *.84*	3.4 *.55*	3.8 *.84*

Table 3. Means and Standard Deviations for Motion Salience Ratings in 6-DOF by Task (Standard deviations appear in Italics).

DISCUSSION

Feigley et al. (1991) advocated specifying training system functional requirements during the weapon system concept development stage, but acknowledged that the definition will continually evolve and need refinement. This work aimed to provide the Marine Corps with additional data to make an informed decision regarding motion-cuing options prior to the development of the AAAV driver training device functional specification.

Primary human sensing mechanisms for detecting self-motion were discussed and it was noted that vestibular and tactile cues are sensed faster than visual cues. The ability to train drivers to recognize physical inertial cues, as opposed to total reliance on visual cues, may facilitate learning to perform time-constrained tasks such as initiating emergency procedures or corrective control inputs. The sooner an operator is alerted to maneuvering motion, disturbance motion, or a malfunction (e.g., loss of brakes, power, or steering, or a loose or thrown track), the faster he can respond. The simulator could capitalize on this phenomenon to train tasks for which vestibular/tactile cues provide advance information.

The analysis then focused on the training effectiveness of motion bases, compared to fixed-base simulation. Boldovici (1992) argued that empirical data to support motion cuing decisions do not exist, but the lack of evidence can not be used as a basis to argue against a motion base: ''Absence of evidence is no evidence of absence'' (Physicist Gary Steigman, cited in Trefil, 1988).

Boldovici (1992) stated that although transfer-of-training research has not demonstrated a transfer superiority that favors motion platforms, much of this research has failed to provide descriptive information on the motion characteristics of the system. Because we lack information regarding the fidelity of the motion platforms in question, the quality of the simulator motion cannot be assessed. One conclusion then is that simulators without motion may be more training effective than simulators which produce "bad" motion. The same inference could probably be made in connection with predictions about simulator sickness and motion: Simulators without motion may be less sickness inducing than simulators with "bad" motion.

Boldovici (1992) suggested that the inability to practice certain tasks under certain conditions without physical motion cues is a good reason to choose between implementing a seat shaker, a g-seat, or a motion base. The process of identifying which tasks can and cannot be practiced without motion involves an empirical question that can be answered by research to examine which motion cues if any, serve a discriminative function for a given task. Estimating the extent to which cues in each axis serve an alerting function is beyond the scope of the current effort, but deserves additional analysis.

The ratings presented in Table 4 indicate that the most salient motion cues are anticipated in the longitudinal, vertical, pitch and yaw axes for many of the tasks considered. Those tasks that received the highest ratings of motion salience (e.g., driving inbound in surf or over rough terrain and recovery aboard ship) are considered high-risk tasks that could potentially result in personnel injury or damage to the vehicle. In reference to Sticha et al.'s (1990) heuristics, since the survey data suggest that since moderate to strong forces are expected in the longitudinal axis during a Sea State of 1, 6-DOF motion may benefit driver training.

The AAAV driver trainer will be used to impart skills for maneuvering the vehicle at sea, in the surf zone and on land. Instructional objectives include embarking and debarking from amphibious ships, transition to and from high-speed water operations, emergency situations and degraded condition driving. The operating environment of the AAAV (amphibious day/night operations in various meteorological conditions and sea states, plunging surf zones and various terrain surfaces, including soft sand, snow, and wet or icy roads) coupled with the vehicle's high speed, high maneuverability operating capabilities, suggests that motion cues may enhance driver training. Additionally, requirements to train emergency procedures and other skills that cannot, or should not, be trained in the actual vehicle may require the use of motion cuing for safety reasons. For example, radical motion forces will likely be generated by emergency conditions in the AAAV, such as loss of a jet engine at high water speeds.

The limited (120 deg, combined [h]) AAAV driver's FOV is perhaps the most persuasive argument in favor of employing force motion cuing for AAAV driver training, because force motion cues become increasingly important when visual cues are limited or otherwise impoverished. Limited or impoverished sensory stimulation in any given modality forces the perceiver to rely upon alternative sensory modalities to obtain necessary information.

Finally, because of safety considerations, training will not be conducted in the actual vehicle above Sea State 3 conditions. Operational requirements dictate however, that AAAV operations be conducted in higher sea states, and this training will only be conducted in the simulator. The restricted FOV, in concert with dangerous operating conditions, and the anticipated salience of motion cues during high risk tasks as indicated by the present analysis were all taken into consideration in the Marine Corps decision to incorporate 6-DOF motion into the AAAV Driver Simulator. Additional analyses will determine the type of motion system (e.g., electro-mechanical vs. electromagnetic) to be procured.

REFERENCES

Albery, W.B. & Kron, G.J. (1978). Motion and force cuing requirements and techniques for advanced tactical aircraft simulation (AGARD Conference Proceedings No. 249). Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development.

Boldovici, J.A. (1992). Simulator motion (ARI Technical Report 961). Orlando, FL: U.S. Army Research Institute.

Butrimas, S.K. (1981). G-seat motion cue generation (NAVTRAEQUIPCEN IH-63). Orlando, FL: Naval Training Equipment Ctr.

DoN (1997). Operational Requirements Document for the Advanced Amphibious Assault Vehicle (NO. MOB 22.1). Washington, DC: Department of the Navy.

DoN (1998). 1998 Department of the Navy Posture Statement. Washington, DC: Department of the Navy.

Feigley, J.M., Beagles, C.A., & Daly, D.J. (1990). The Advanced Amphibious Assault (AAA) Program: An early consideration of required training systems. In, Proceedings of the 12th Interservice/Industry Training Systems Conference (pp. 474-477).

Gibson, J. J. (1966). The senses considered as perceptual systems. Houghton Mifflin.

Jacobs, J. W., Prince, C., Hays, R. T., & Salas, E. (1990). A meta-analysis of the flight simulator training research. Orlando, FL: Naval Training Systems Center.

Matheny, W. G., Lowes, A. L., & Bynum, J. A. (1971). To move or not to move? The problem of motion in training simulators. Naval training Device Center 25th Anniversary Commemorative Technical Journal. Orlando, FL: Naval Training Device Center.

Mooij, H.A. (1987). Technology involved in the simulation of motion cues: The current trend. AGARD Aerospace Medical Symposium on Motion Cues in Flight Simulation and Simulator Sickness. Neuilly-sur-Seine, France: Advisory Group for Aerospace Research and Development

NAWCTSD (1998). Advanced Amphibious Assault Vehicle Training System Acquisition Management Plan. Orlando, FL: Naval Air Warfare Center Training Systems Division.

Reese, W.C. (1991). The advent of tracked driver trainer simulation in the United States Army. Proceedings of the International Training Equipment Conference (p. 148-153).

Sticha, P.J., Singer, M.J., Blacksten, H.R., Morrison, J.E., & Cross, K.D. (1990). (ARI Technical Report 914). Research and methods for simulation design: State of the art. Orlando, FL: U.S. Army Research Institute.

Trefil, J. (1988). Greetings from the antiworld. Smithsonian, 29(3), 61-68.

USMC (1998). Concepts & Issues '98: Building a Corps for the 21st Century Washington, DC: Headquarters, U. S. Marine Corps.