Training Effectiveness of Dismounted Infantry Simulation

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ABSTRACT

The U.S. Army recently fielded a dismounted infantry simulator to train small-unit tactical skills and to link small-unit simulation training with armored vehicle simulation. The Dismounted Soldier Training System (DSTS) uses a helmet-mounted display and controllers mounted to the surrogate weapon to allow Soldiers to interact with the virtual environment. Creating effective simulation for dismounted infantry is difficult because replicating the sensory-motor affordances for physical orientation and situational awareness and maintaining inter-personal communication are technically complex but essential to execution of small-unit tactical skills. In order to determine the extent to which DSTS trainability was impacted by sensory-motor orientation and communication issues, Soldier performance data was collected during two large-scale capabilities experiments. In both experiments, Soldiers conducted infantry small-unit tasks in DSTS and provided feedback on the similarity and difficulty of performing individual skills (e.g., walk/run, know location of others, and communicate with others). In particular, DSTS capabilities to provide visual identification, auditory localization (including communication), and interaction with the environment were analyzed. For comparison purposes, data from a motion-capture-simulation system was also collected during one of the experiments. The potential advantages of motion-capture systems hinge on the use of natural locomotion to translate interaction in the virtual environment. The results indicated that DSTS visual identification capabilities were mostly similar to but somewhat more difficult than live performance. However, auditory localization and interaction with environment capabilities were dissimilar to and more difficult than live performance. The motion-capture system results were consistent with the DSTS results except on ratings for movement capabilities. Taken together, the results suggested that current dismounted-infantry simulation technologies do not fully provide the basic sensory-motor orientation and communication capabilities that are critical for dismounted simulation trainability. The results also identified specific simulation capabilities that must be addressed in order to produce effective dismounted-infantry simulation.

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INTRODUCTION

The U.S. Army recently fielded a dismounted infantry simulator to train small-unit tactical skills and to link small-unit simulation training with armored vehicle simulation. The Dismounted Soldier Training System (DSTS) uses a helmet-mounted display and controllers mounted to the surrogate weapon to allow Soldiers to interact with the virtual environment. The use of dismounted-infantry simulation is intended to enhance training, replicate battlefield conditions, balance resources, and sustain readiness. Virtual simulation could provide a useful tool to enhance the execution of individual and collective tasks because of the capability to recreate situations and environments that cannot be replicated in live training and the ability to rapidly modify training conditions. DSTS will also allow ground troops to participate in a common virtual environment with armor and aviation. The Infantry Soldier focuses on basic tasks when in his operational environment. He moves, he shoots, and he communicates. At a minimum, simulation training must exercise these skills at both the individual and collective level. Training individual basic skills (i.e., move, shoot, and communicate) may require immersive simulation in order to address the psychomotor requirements of such skills. In order to determine the extent to which DSTS trainability was impacted by sensory-motor orientation and communication issues, Soldier performance data was collected during two large-scale capabilities experiments.

Dismounted Soldier Training System

DSTS evolved from a previous Army Science and Technology Objective to develop virtual environments for dismounted Soldiers (Knerr, 2007). DSTS suites consist of nine man-wearable Virtual Soldier Manned Modules (VSMM), five desktop Virtual Soldier Multi-Functional Work Stations (VSMW), a Semi-Automated Force (SAF) workstation, an Exercise Control (EXCON) workstation and an After Action Review (AAR) station (see Figure 1). DSTS surrogate weapons mix includes: 5 x M4 Rifles, 2 x M4/M320 Rifle/Grenade Launchers, and 2 x M249 Machine Guns. The DSTS virtual environment is generated in Virtual Battle Space 2 (VBS2) and was initially fielded with three terrain databases. Multiple DSTS suites can be networked together for Infantry Platoon operations and eventually will have the capability of networking to the Close Combat Tactical Trainer. The system is designed to be portable.

The VSMM is the immersive interface for DSTS. Each Soldier wears a backpack computer that generates the virtual environment and a helmet-mounted display (HMD) to view the virtual environment. The HMD provides the Soldier with a 360 degree horizontal field of regard, a 180 degree total vertical field of regard, a 60 degree instantaneous horizontal field of view (FOV), and a 45 degree instantaneous vertical FOV. Full peripheral vision is not achieved. Body and head sensors attached to the Soldier (three sensors per arm and one sensor per leg) translate physical movement of arms and head into virtual movement of arms and head.

Soldiers are matched to pre-determined generic avatars in the virtual environment. Virtual locomotion is controlled by a thumbstick located on the vertical handgrip of the surrogate weapon. Rate of movement is dictated by the amount of pressure imposed on the thumbstick in combination with the position of the weapon (i.e., high ready or low ready). Soldiers' physical positions from standing to kneeling to prone are captured by leg sensors and mirrored by their avatar in the virtual environment. The Soldier is able to move in any direction within the virtual environment by physically turning the body towards the desired direction of travel. Low crawling or crouching and moving is accomplished by activating the thumbstick while physically in the prone or kneeling position.

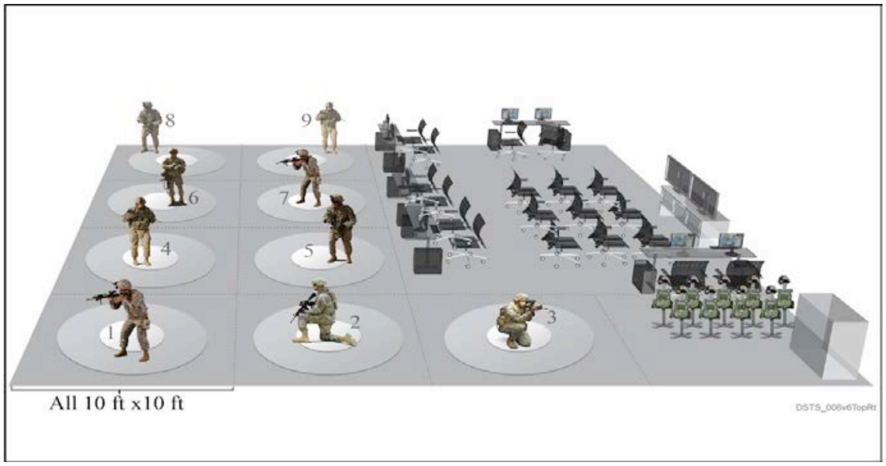

Figure 1. Example Dismounted Soldier Training System Configuration

Soldiers communicate through a headset and microphone, which enable him to hear voice, radio, and battlefield effects (e.g., gunshots, explosions, ambient noise, etc.). The communication among Soldiers is on an open network, and Soldiers hear all communications on the open network regardless of the proximity to other Soldiers. Radio communication between teams or between the Squad Leader and the Platoon Leader was accomplished with push-to-talk buttons located on the communications junction box at the front of the sensor harness. Multiple radio channels were available to the units conducting training to replicate actual radio capabilities.

The surrogate weapons available replicate what an Infantry Squad would carry as individual weapons; the M4 Rifle, the M4/M320 Rifle/Grenade Launcher, and the M249 Machine Gun. These weapons closely replicated the actual weapons in size, weight, and functionality. A visual facsimile of the optic was displayed in the HMD when a pressure plate located in the buttstock of the weapon indicated that the Soldier had placed the weapon in the pocket of the shoulder in a normal firing position.

Sensorimotor Invariants for Training

Creating effective simulation for dismounted infantry is difficult because replicating the sensory-motor affordances for physical orientation and situational awareness and maintaining inter-personal communication are technically complex but essential to execution of small-unit tactical skills. One way to determine dependence between the capabilities of simulation and the skills being trained is to consider the affordances provided by the simulation. In general, affordances are functional properties of the environment or objects in the environment that prescribe sensorimotor interaction (Gibson, 1979; Stoffregen, 2003). Affordances imply there is a minimum set of properties the simulation must provide in order to allow a given skill to be developed. This minimum set of properties, or invariants, define the sensorimotor properties of a skill that must be present in the training environment in order to successfully transfer the skills to live performance (Lintern, 1991).

Although not thoroughly studied, the invariants for Squad collective skills must allow individual Soldiers to maintain physical orientation in the environment, maneuver in the environment, interact with objects in the environment, communicate with others in the environment, and coordinate action with others (e.g., Knerr, 2007). Much of the early research on the development of dismounted-infantry simulation (e.g., Knerr et al., 2002; Knerr et al., 2003; Lampton & Jerome, 2010; Pleban, Eakin, & Salter., 2000) has identified four types of system capabilities that are crucial for trainability and that could help define training invariants. First is the ability to move (individually and collectively) in the environment to include individual movement techniques (e.g., high crawl and low crawl). Second is the ability to interact with objects in the environment (e.g., open a door). Third is the ability to visually identify terrain, objects, and individuals in the environment. Fourth is the ability for three-dimensional audition to include auditory localization and proximal communication.

It is important to note that these potential training invariants do not represent specific military or tactical skills (e.g., firing a weapon or operating equipment) but do support the types of tactical skills necessary for dismounted-infantry operations. Likewise, these invariants do not directly address leadership skills. Rather, some training invariants represent collective skills (e.g., the ability to move in formation). These collective skills indicate the unit's ability to responds to Leaders' commands and provide important information for Leaders' decision making. In order to train leadership skills in DSTS, the invariants for collective skills must be satisfied.

METHOD

Data was collected during two system-capabilities experiments. The first was a pre-fielding user assessment of DSTS. The second experiment was the Army Expeditionary Warrior Experiment – Bold Quest 2012. Bold Quest was sponsored by Joint Forces Command to evaluate Infantry squad training systems. Bold Quest included data on two immersive dismounted infantry simulations: DSTS and Small Unit Virtual Immersion System (VIRTSIM). Both experiments were conducted at Fort Benning, GA. As part of the experiments, Soldiers rated the degree to which critical tactical tasks were *similar* or *difficult* to perform in the simulator as compared to live. Participants provided additional input as part of the larger experiments, but only the relevant ratings of system capabilities were analyzed for the present paper.

The specific system capabilities used for the present analysis represented discrete sensorimotor skills identified in previous research on dismounted-infantry simulation as critical for training effectiveness (e.g., Knerr, 2007; Knerr & Lampton, 2005; Lampton & Jerome, 2010; Pleban et al., 2000). These system capabilities were organized into three categories: *Auditory Localization*; *Visual Identification*; *Interaction with the Physical Environment*. These categories of system capabilities are not invariants in the true sense. That is, they are not perceptual regularities of the environment that indicate a given affordance. However, they are sensorimotor regularities of many Infantry squad tasks and, as such, represent training invariants for the virtual environment. That is, in order for dismounted-infantry simulation to provide effective training, it must be based on satisfying these sensorimotor regularities (Gross, Stanney, & Cohn, 2005). Examples of specific system capabilities that were assessed include the ability to determine the source of enemy fire by sound, the ability to determine other team/squad members' position, and the ability to maneuver around obstacles.

Participants

Each capabilities experiment used organic Infantry squads. For the DSTS user assessment, two squads from the same Armored Brigade Combat Team were used. The Platoon Leader also provided data for a total of 19 participants. The ranks ranged from Private First Class to Sergeant First Class to Second Lieutenant. Participants from Bold Quest 2012 included one U. S. Army squad, one Royal Canadian Regiment squad, and one U. S. Marine Corps squad. The Army squad was from an experimental forces command while the other two squads were from the operational forces. Because U.S. Marine Corps squads contain 13 members, the immersive systems were modified to allow all members to participate. By contrast, the Royal Canadian Regiment traditionally uses 8-member squads. With these compositions of squads and the addition of data collected from the respective Platoon leaders, the total number of participants from Bold Quest 2012 was 33. The ranks of the squad members ranged from Private First Class to Sergeant First Class, and the Leaders were all First Lieutenants.

Materials and Procedure

In general, the method was consistent across squads and training experiments. Each squad was given a 2-hour block of familiarization training in the immersive system. The squad then executed some combination of offensive, defensive, and area reconnaissance missions over the course of four days. The squad completed at least two training missions each day. At the end of each mission, the squad was given an after-action review by the Platoon Leader, and all members of the squad completed a system-capabilities checklist at the end of each training day. The system-capabilities checklist listed 56 individual and collective actions that support Infantry tasks (e.g., move up and down stairs) and that should be simulated by the immersive system (Pleban, et. al, 2000). For each system capability, the participants used a 3-point scale to indicate how similar (i.e., Not Similar, Somewhat Similar, or Exactly Like) each capability was to perform in the immersive system compared to live performance. A 3-point scale was also used to indicate how difficult (i.e., Less Difficult, About the Same, or More Difficult) each capability was to perform in the immersive system as compared to live. Although participants rated all 56 system capabilities, only the 22 capabilities related to *Auditory Localization*; *Visual Identification*; *Interaction with the Physical Environment* are reported here (see Table 1).

For the DSTS user assessment, each of the two squads had eight total training missions using DSTS: four offensive missions and four defensive missions in both urban and woodland environments. For Bold Quest, each squad only participated in two of three types of training missions (i.e., offensive, defensive, or area reconnaissance), and each squad only had two or three iterations of each mission. Each squad participated in both DSTS and VIRTSIM. So, for example, the U.S. Army squad executed area reconnaissance missions in DSTS and then executed offensive missions in VIRTSIM. In addition, to the specific training missions, each squad engaged in other training in the immersive system during the four days of training such as fire team drills and room clearing drills.

RESULTS

Because the focus for the analysis was on the Army-fielded system (i.e., DSTS), the results are primarily presented using only the data from DSTS. Data from VIRTSIM usage was used to compare the generality of the results from DSTS. More specifically, VIRTSIM data was used to determine if any shortcomings or advantages of DSTS in supporting training invariants was due to the mode of motion translation (i.e., thumbstick control vice motion capture). As a result, only areas in which VIRTSIM results significantly differed from DSTS results will be reported for VIRTSIM data. Obviously, this data is only based on responses from the Bold Quest 2012 experiment whereas the DSTS system capabilities data is based on responses from both experiments.

Participant ratings of both similarity and difficulty were aggregated across experiments, individuals, iterations, mission types, and environments for each immersive system. Non-parametric analyses of the resulting frequencies were conducted to determine the patterns of ratings across the system capabilities. The results were then classified based on the ratings of similarity to determine the sufficiency of the categories of training invariants in DSTS. That is, those system capabilities that were rated as being “Exactly Like” real life by the majority of responses were classified together and likewise for those system capabilities rated as “Somewhat Similar” and rated as “Not Similar.” By identifying how many capabilities in each category of training invariants (i.e., Auditory Localization, Visual Identification, and Interaction with the Physical Environment) were classified in each type of rating, it was possible to determine how sufficient DSTS was in training critical elements of Infantry tasks. Each system capability was then classified by its rating of difficulty (i.e., More Difficult, About the Same, and Less Difficult). The ratings of difficulty were used to indicate possible explanations for the similarity ratings. That is, for example, if a given system capability was classified as “Exactly Like” the real world, the capability should be easily performed in DSTS (i.e., rated About the Same on difficulty).

Training Invariants in DSTS

Table 1 presents the classification of system capabilities. Table 2 presents the frequencies and statistical test for each system capability for each type of rating. As indicated by Table 1, the ability to stand, kneel, and assume the prone position was the only capability that DSTS provided that was exactly like the real world. This capability was as easy to do in DSTS as it was in the real world. Likewise, all of the capabilities associated with Visual Identification were rated as being somewhat similar to the real world. This result indicates that the ways in which visual information was translated in DSTS was similar to the real world. That said, the ability to identify individuals outside of one’s team and squad was more difficult than in real life. This result is somewhat misleading because the identification of known individuals (i.e., squad members) is augmented by tags in the virtual environment and is not based on the physical features of the virtual entity. So, when identification of other people in DSTS is based solely on the physical features of the avatar, visual identification is difficult.

Table 1. Classification of DSTS System Capabilities Based on Ratings of *Similarity* and *Difficulty*

Similarity Rating Classification	*Training Invariant Category*	*Difficulty Rating*
Exactly like real world		
Stand, Kneel, Prone	Interact with Physical Environment	About the Same
Somewhat similar to real world		
Look	Visual Identification	About the Same
Identify objects	Visual Identification	About the Same
Identify terrain features	Visual Identification	About the Same
Identify own fire team members	Visual Identification	About the Same
Identify non-combatants	Visual Identification	More Difficult
Identify combatants	Visual Identification	More Difficult
Know location of team members	Visual Identification	More Difficult
Not Similar to real world		
Communicate with own squad/fire team	Auditroy Localization	About the Same
Communicate with other fire team	Auditroy Localization	More Difficult
Determine origin/direction of enemy fire	Auditroy Localization	More Difficult
Open/close doors	Interact with Physical Environment	More Difficult
Walk, Run	Interact with Physical Environment	More Difficult
Move (Low Crawl, 3-5 sec rush)	Interact with Physical Environment	More Difficult
Step over	Interact with Physical Environment	More Difficult
Avoid collisions	Interact with Physical Environment	More Difficult
Climb	Interact with Physical Environment	More Difficult
Interact with objects	Interact with Physical Environment	More Difficult
Undetermined		
Move up and down stairs	Interact with Physical Environment	About the Same
Maintain balance while moving	Interact with Physical Environment	About the Same
Maintain orientation within simulation	Interact with Physical Environment	More Difficult
Maintain position within formation	Interact with Physical Environment	More Difficult

The results presented in Table 1 also indicated that *all* of the Auditory Localization system capabilities were rated as "Not Similar" to the real world as were most of the Interact with the Physical Environment capabilities. Not surprising, all of these capabilities except one were rated as being more difficult to perform in DSTS than in the real world, which could account for the low ratings of similarity. The system capabilities that were categorized as "Undetermined" were those capabilities for which there was no significant difference on the frequencies of similarity ratings. Apparently, participants had different experiences with these capabilities in DSTS. Interestingly, these capabilities mostly applied to the ability to maintain orientation in the virtual environment.

Table 2. Response Frequencies for *Similarity* and *Difficulty* Ratings for DSTS

System Capability	Similar				Difficult			
	Exactly	Somewhat	Not	χ^2	Less	About the Same	More	χ^2
Auditory Localization								
Communicate with own squad/fire team	15	18	32	7.60	26	11	29	8.45
Communicate with other fire team	2	10	20	15.25	6	6	20	12.25
Determine origin/direction of enemy fire	6	13	46	42.12	8	9	47	46.34
Visual Identification								
Look	25	26	7	11.83	1	33	24	28.17
Identify objects	9	16	2	10.89	0	20	7	22.89
Identify terrain features	14	24	8	8.52	4	26	16	15.83
Identify non-combatants	0	22	8	24.80	0	12	18	16.80
Identify combatants	0	19	11	18.20	0	12	18	16.80
Identify own fire team members	6	33	27	18.27	19	31	14	7.16
Know location of team members	10	30	26	10.18	17	19	30	4.45
Interact with the Physical Environment								
Stand, Kneel, Prone	54	45	5	39.25	3	93	8	147.60
Maintain balance while moving	27	19	13	5.02	4	42	13	40.10
Maintain orientation within simulation	18	21	23	0.61	0	23	39	37.19
Move up and down stairs	17	11	24	4.88	4	23	25	15.50
Maintain position within formation	14	12	25	5.76	2	18	31	24.82
Open/close doors	14	10	29	11.36	2	16	35	31.06
Walk, Run	11	17	31	10.71	9	22	27	8.93
Move (Low Crawl, 3-5 sec rush)	6	10	23	12.15	5	11	23	12.92
Step over	4	6	21	16.71	2	2	23	32.67
Avoid collisions	4	12	46	48.13	4	6	52	71.35
Climb	2	5	36	49.44	3	2	38	58.65
Interact with objects	0	0	24	48.00	0	0	24	48.00

Comparison of DSTS and VIRTSIM

Table 3 presents those system capabilities on which the ratings of similarity for DSTS differed from ratings for VIRTSIM. Again, the purpose of this analysis was to determine how the modes of locomotion in the virtual environment impacted the enactment of training invariants in DSTS. Because VIRTSIM utilizes motion-capture technology to translate individual movements in three-dimensional space into movements in the virtual environment, movement in the virtual environment is much more natural. Not surprisingly, system capabilities associated with moving in the virtual environment were rated as more similar in VIRTSIM than in DSTS. The differences in Interact with Physical Environment capabilities indicated that maintaining orientation in the virtual environment was more similar to the real world in VIRTSIM than in DSTS. Interestingly, one Auditory Localization capability was also rated more similar in VIRTSIM than DSTS. This result was likely due to the fact that proximal communication was possible in VIRTSIM because squad members could physically stand next to one another and directly talk to one another (i.e., talk without the use of the headset device). The results for the comparison of DSTS and VIRTSIM indicated that the ability to freely move in physical space while interacting in the virtual environment did account for some of the difficulties in training invariants but not all.

It is important to note that Visual Identification system capabilities were not included in this analysis even though some differences in similarity ratings were found. The Bold Quest 2012 experiment required VIRTSIM to incorporate aspects of VBS2 into the native VIRTSIM virtual environment. Even though VBS2 entities could be rendered in the virtual environment, it was determined that there were significant modifications to the VIRTSIM visual capabilities. As a consequence, valid comparisons between DSTS and VIRTSIM visual capabilities may not be possible. Moreover, because the DSTS-VIRTSIM comparisons were made in order to determine the impact of natural movement in dismounted infantry simulation, it did not make sense to compare visual capabilities of the two systems, especially given that Visual Identification was fairly well represented by DSTS.

Table 3. Response Frequencies for *Similarity* Ratings that Differed Between DSTS and VIRTSIM

System Capability		Similar			
		Exactly	Somewhat	Not	χ^2
Auditory Localization					
Communicate with own squad/fire team	DSTS	0	9	18	5.12
	VIRTSIM	0	19	11	
Interact with the Physical Environment					
Maintain balance while moving	DSTS	5	12	10	25.29
	VIRTSIM	24	5	0	
Maintain position within formation	DSTS	0	5	19	18.66
	VIRTSIM	8	18	8	
Walk, Run	DSTS	0	0	27	56.00
	VIRTSIM	13	16	0	
Move (Low Crawl, 3-5 sec rush)	DSTS	0	3	22	38.57
	VIRTSIM	15	7	0	

DISCUSSION

The purpose of the research reported here was to determine the extent to which dismounted infantry simulation support sensorimotor invariants that are crucial for training critical infantry tasks. These so-called *training invariants* are not themselves trainable skills. Rather, training invariants are sensorimotor properties of the virtual environment and the simulator interface that allow for the execution of trainable skills. For example, react to contact is a tactical skill that should be trainable in dismounted infantry simulation. The ability to train react to contact depends on how well dismounts can identify the origin of fire in the virtual environment. The data reported in this paper addressed the ability of DSTS to support three important training invariants: Auditory Localization, Visual Identification, and Interaction with the Physical Environment.

Overall, Visual Identification in DSTS was determined to be similar to the real world although some of the system-capabilities associated with Visual Identification were rated as being more difficult to execute in DSTS than in the real world (e.g., Identify non-combatants). Visual Identification is an important aspect of maintaining orientation and awareness in the environment. The fact that DSTS provided effective Visual Identification indicated that a significant portion of training invariants can be satisfied. By contrast, most of the difficulties with training invariants in DSTS were attributed to Auditory Localization and Interaction with the Physical Environment. All of system-capabilities associated with Auditory Localization and most of the system-capabilities associated with Interaction in the Physical Environment were determined not to be similar to the real world. Most of these system capabilities were also rated as more difficult to perform in DSTS than in the real world.

The advantages and limitations implied by the results indicate the types of training for which DSTS is currently best suited. Although the original intent for DSTS was to be part of the Combined Arms Tactical Training environment, the difficulties in Auditory Localization and Interaction with the Physical Environment suggest that training in large complex environments would be difficult with DSTS. Likewise, coordinating with and interacting with mechanized assets in the virtual environment would also be difficult. From the perspective of training invariants, DSTS could be effectively used to train smaller groups (i.e., fire team or buddy team) in part-task-type training. For example, DSTS would be an effective means to get multiple repetitions of fire team/buddy team move-and-shoot drills or room clearing drills in advance of squad-level (or higher) training events.

Interestingly, the ability to move freely in the physical world only partially accounted for the difficulties on Auditory Localization and Interaction with the Physical Environment. While free movement appears to be a significant advancement in dismounted infantry simulation, other technological improvements may be more important to address training invariants. The results reported here indicated that Auditory Localization needed significant improvement. Technology that allows for three-dimensional audition could address some of these gaps. However, a much more complex technology solution may be needed for a simpler real-world issue. The open network communications that are currently used in DSTS and other dismounted infantry simulators make it impossible to distinguish between proximal and distal communications. That is, because every person in a DSTS suite hears all voice utterances from all other people in the suite, it is impossible to determine if the person talking is near or many meters away. Likewise, it is possible to whisper to a team member who is located 100 meters away and in another building in the virtual environment. Certainly, units training in DSTS can develop procedures to deal with the issues of proximal-distal communication, but those procedures may significantly change the way communication is done in the real world and lead to negative training. Rather, a technology will need to be developed that limits what communications can be heard in the virtual environment.

In addition to communications, the ability to interact with physical objects in the real world will need to be improved in dismounted infantry simulations in order to address training invariants. On the one hand, simply physical interactions such as opening a doorknob can be simulated with a "work-around" without any impact to training. In DSTS, opening a door is done either with a hand gesture that resembles turning a knob or with a series of button presses on the controller. On the other hand, the ability to feel a wall while taking cover or to step over objects while taking actions on an objective may significantly impact training. There are few effective work-arounds for Interactions with the Physical Environment that are needed to maintain awareness or orientation. Humans depend on tactile and kinesthetic cues to maintain orientation, and when those cues are absent, there is a cost to performance. Immersive simulation cannot replicate those cues. It may be the case that effective dismounted infantry simulation is only possible with augmented-reality technology that provides Soldiers a more concrete link to the physical world.

In summary, developing dismounted infantry simulation presents significant technological challenges because it is difficult to take the Soldier out of the physical environment. That difficulty is linked to the sensorimotor requirements of executing tactical tasks (i.e., training invariants). Current dismounted infantry simulation systems do provide some training benefit but still need to better represent training invariants.

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