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# Blue Force Tracking for Dismounted Soldiers

## *Experiments to Evaluate its Effects on Soldier Performance*

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## Abstract

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Today's Blue Force Tracking (BFT) systems use Global Positioning System (GPS) to track individual soldiers. In two experiments, we investigated the effects of BFT on soldier performance using a first-person computer simulation. In Experiment 1, 36 participants led a section to locate and support another force under enemy contact. They did the task with a Two Dimensional (2D) map with Accurate BFT, Inaccurate BFT, or No BFT. The results showed that when using BFT, soldiers were faster in engaging the enemy but other performance variables were not significant. They also used their BFT map more frequently compared to the No BFT condition. The Inaccurate BFT did not negatively affect performance. In Experiment 2, participants led a firebase in similar hasty attack missions. In each mission, a unique event could affect the decision to attack. Participants used no BFT, a 2D map with BFT, or three different augmented reality displays. The BFT again could have 100% signal accuracy or some inaccuracy. The results showed that having BFT supported more accurate event detection and marginally faster event detection times. An accurate BFT also resulted in faster attack decisions in some conditions. However, this did not translate to more accurate decisions. BFT accuracy did not affect the participants' ability to accurately locate and map blue force positions, but they had more confidence in their ability with accurate BFT systems. There was no additional benefit for augmented reality BFT over a BFT map system. The studies suggest that BFT supports mission performance even when it is not perfectly accurate, and augmented reality systems have limited benefit relative to a handheld system, at least for the tasks examined.

## Significance to Defence and Security

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The Canadian Army is acquiring a Blue Force Tracking (BFT) capability for all dismounted soldiers with the Integrated Soldier System Suite (ISS-S). In both studies reported, we examine soldier performance when using a BFT that perfectly displays blue force positions and a BFT with GPS error. The results suggest that BFT supports soldier performance by providing them with better situation awareness that can result in faster detection of events and faster decision-making. These benefits were evident even when we simulated realistic GPS errors in blue force positions. In the second study, we simulated BFT in an augmented-reality display. The results suggested that BFT presented through Augmented Reality (AR) did not have any additional benefits over a traditional map-based BFT system. Thus, more research needs to be conducted to determine whether the Canadian Armed Forces (CAF) should invest in future augmented-reality BFT systems for dismounted soldiers.

## Résumé

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Les systèmes actuels de suivi de la force bleue (SFB) utilisent le système de localisation GPS pour suivre séparément chaque soldat. Dans le cadre de deux expériences, nous avons étudié les effets du SFB sur le rendement du soldat au moyen d'une simulation informatique à la première personne. Au cours de la première expérience, 36 participants ont dirigé une section pour trouver et appuyer une autre force en contact avec l'ennemi. Ces derniers ont exécuté cette tâche au moyen d'une carte 2D avec un SFB précis, un SFB imprécis ou sans SFB. Les résultats ont indiqué que les soldats qui utilisaient le SFB avaient engagé le combat avec l'ennemi plus rapidement, mais que d'autres variables de rendement n'avaient pas eu une incidence importante. Ils avaient aussi utilisé leur carte plus fréquemment que ceux qui ne disposaient pas du SFB. L'utilisation du SFB imprécis n'a pas nui au rendement. Lors de la seconde expérience, les participants ont dirigé une base de feu dans le cadre de semblables missions d'attaque improvisée. Durant chaque mission, un événement unique pouvait influencer la décision d'attaquer. Les participants n'utilisaient pas le SFB ou bien utilisaient une carte 2D avec SFB ou encore trois affichages distincts à réalité augmentée. Le SFB pouvait avoir une précision des signaux de 100 % ou certaines imprécisions. Les résultats ont démontré que l'utilisation du SFB facilitait une détection d'événement plus précise et améliorait légèrement le temps de détection d'événement. Dans certaines conditions, un SFB précis a aussi entraîné une décision d'attaquer légèrement plus rapide. Par contre, cette décision n'était pas plus précise. La précision du SFB n'a pas eu d'incidence sur la capacité du participant de localiser et cartographier avec exactitude la position de la force bleue, mais elle a accru son niveau de confiance. Le SFB avec réalité augmentée n'offrait aucun autre avantage par rapport à un système cartographique de SFB. Nos études donnent à penser que le SFB favorise le rendement des missions, même lorsqu'il n'est pas tout à fait précis et que les systèmes de réalité augmentée offrent des avantages limités par rapport à un système cartographique portable, du moins dans le cadre des tâches à l'étude.

## Importance pour la défense et la sécurité

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Avec la suite d'équipement intégré du soldat (S-ÉIS), l'Armée canadienne acquiert une capacité de suivi de la force bleue (SFB) pour tous les soldats débarqués. Dans les deux études qui font l'objet du présent rapport, nous avons examiné le rendement d'un soldat qui utilise un SFB affichant précisément la position de la force bleue ou un SFB avec erreurs de géolocalisation. Les résultats laissent croire que le SFB favorise le rendement des soldats en leur procurant une meilleure connaissance de la situation, ce qui peut entraîner une détection d'événement et une prise de décision plus rapide. Les avantages étaient manifestes, même lorsque nous avons simulé des erreurs de géolocalisation réalistes dans la position de la force bleue. Dans la seconde étude, nous avons simulé le SFB grâce à un affichage à réalité augmentée. Les résultats ont indiqué que la présentation du SFB au moyen de la réalité augmentée n'offrait pas d'avantages par rapport à un système cartographique de SFB traditionnel. Par conséquent, il faudra effectuer d'autres recherches pour déterminer si les Forces armées canadiennes (FAC) devraient investir dans de futurs systèmes de SFB à réalité augmentée pour les soldats débarqués.

# Table of Contents

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Abstract . . . . .	i
Significance to Defence and Security. . . . .	i
Résumé . . . . .	ii
Importance pour la défense et la sécurité . . . . .	ii
Table of Contents . . . . .	iii
List of Figures . . . . .	v
List of Tables . . . . .	vi
Acknowledgements . . . . .	vii
1 Introduction . . . . .	1
1.1 The Use of Blue Force Tracking in the Military . . . . .	1
1.2 Research on Blue Force Tracking . . . . .	2
1.3 BFT Signal Accuracy. . . . .	4
2 Experiment 1 . . . . .	7
2.1 Method . . . . .	7
2.1.1 Participants. . . . .	7
2.1.2 Apparatus . . . . .	7
2.1.3 Design . . . . .	8
2.1.3.1 Independent Variables . . . . .	8
2.1.3.2 Dependent Variables. . . . .	8
2.1.4 Mission Scenario . . . . .	9
2.1.5 Procedure . . . . .	11
2.2 Results . . . . .	12
2.3 Discussion. . . . .	14
3 Experiment 2 . . . . .	16
3.1 Method . . . . .	17
3.1.1 Participants. . . . .	17
3.1.2 Apparatus . . . . .	18
3.1.3 Design . . . . .	18
3.1.4 Stimuli . . . . .	18
3.1.4.1 No BFT . . . . .	18
3.1.4.2 BFT Map . . . . .	19
3.1.4.3 AR-Boxes. . . . .	19
3.1.4.4 AR-Dots . . . . .	20
3.1.4.5 AR-Ribbon . . . . .	20
3.1.5 Scenarios and Task. . . . .	21
3.1.6 Procedure . . . . .	23
3.2 Results . . . . .	23

3.2.1	Attack Decision . . . . .	24
3.2.1.1	Attack Decision Accuracy. . . . .	24
3.2.1.2	Attack Decision Time . . . . .	25
3.2.2	Event Awareness . . . . .	27
3.2.2.1	Event Awareness Accuracy . . . . .	27
3.2.2.2	Event Awareness Time . . . . .	28
3.2.3	Friendly Fire . . . . .	29
3.2.4	Geo-positional Awareness . . . . .	29
3.2.4.1	Euclidean Distance of Assault Teams . . . . .	29
3.2.4.2	Confidence Ratings for Mapping Entities . . . . .	30
3.3	Discussion. . . . .	31
3.3.1	Limitations. . . . .	33
3.3.2	Lessons Learned. . . . .	34
3.3.3	Future Research . . . . .	35
4	Conclusion. . . . .	37
	References . . . . .	38
	List of Symbols/Abbreviations/Acronyms/Initialisms. . . . .	42

## List of Figures

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Figure 1:	A screenshot of participant's character as it approaches Encounter 2 (left) and an example of the BFT showing friendly forces situated in the north building (right).	11
Figure 2:	An example of the No BFT condition.	19
Figure 3:	Examples of the eight BFT conditions.	21
Figure 4:	Attack decision time (shown as z-score) for each BFT condition, when signal accuracy was perfect.	26
Figure 5:	Attack decision time (shown as z-score) for each BFT condition, when signal accuracy was imperfect.	26
Figure 6:	Event awareness time (shown as a z-score) for each BFT condition, when signal accuracy was perfect.	28
Figure 7:	Event awareness time (shown as a z-score) for each BFT condition, when signal accuracy was imperfect.	29
Figure 8:	Confidence ratings for mapping entities for each BFT condition when signal accuracy is perfectly accurate.	30
Figure 9:	Confidence ratings for mapping entities for each BFT condition when signal accuracy is inaccurate.	31

## List of Tables

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Table 1:	A list of the dependent variables for Experiment 1. . . . .	9
Table 2:	Means (Ms) and Standard Errors (SEs) for each dependent measure in the No BFT, Inaccurate BFT and Accurate BFT conditions. . . . .	13
Table 3:	A list of the critical events in each mission presented in Experiment 2. . . . .	22
Table 4:	A list of the dependent variables used in Experiment 2.. . . .	24
Table 5:	Attack decision accuracy (%) and rank for each condition. . . . .	25
Table 6:	Event awareness accuracy (%) and rank for each condition. . . . .	27
Table 7:	Percentage of friendly-fire instances across BFT conditions. . . . .	29

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# 1 Introduction

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For military commanders, having information about friendly force (i.e., blue force) positions is central for planning, adapting to mission changes, managing resources, and coordinating support when help is required. For the Canadian Armed Forces (CAF) today, maintaining friendly force Situation Awareness (SA) is still primarily accomplished through radio and chat communications (e.g., Transverse Chat) and map boards [1]. In contrast, since 2002, the United States (US) military has been using Blue Force Tracking (BFT) technology to maintain positional awareness of blue forces in theatre. BFT uses Global Positioning System (GPS) information to track friendly forces through a computer [2]. In the near future, through the Integrated Soldier System Project (ISSP) [3] and the Land Command Support Systems (LCSS) project [4], BFT systems will be introduced to the CAF. By providing real-time positional information of land forces, BFT should provide better overall SA of the battlefield.

The benefit of BFT has been largely anecdotal, based on the reports of commanders who have used BFT systems in theatre [5]. Only a few studies have investigated the impact of BFT using metrics relevant to mission performance or human performance. Moreover, we are not aware of any studies in which BFT information is presented to dismounted soldiers through a head-mounted Augmented Reality (AR) system, even though such systems are in development [6].

In this report, we describe two experiments that simulated BFT for dismounted ground forces. In Experiment 1, participants led a section called to support another nearby blue force under contact. The participants used a digital Two-Dimensional (2D) map with BFT to support navigation and to help identify the friendly force under contact. The BFT could be perfectly accurate or it had some GPS errors in locating the positions of friendly forces. In Experiment 2, participants led the firebase in a hasty attack on an enemy compound. The attacks were conducted with BFT using either a digital 2D map or with various AR simulations.

## 1.1 The Use of Blue Force Tracking in the Military

BFT is a generic term that refers to any technology that allows military operators to locate the position and movement of other friendly forces [7] [8]. A typical BFT system consists of the tracking device that determines an individual's location and identification, a transceiver, a communications network and a device to present the interface. BFT typically uses GPS technology to track blue force locations [9]. BFT devices can be categorized into two types: (a) one-way BFTs that transmit positional data and (b) two-way BFTs that both send and receive positional data. One-way systems transmit position and identity data of the individual soldier to commanders, whereas two-way systems can provide all users with a broader picture of the battlespace by integrating and disseminating the blue force situation from many systems and tracking devices [7].

Sweeney [7] suggests that at least twelve different BFT systems were used by the US military during the conflicts in Iraq and Afghanistan. These systems can be categorized into: conventional, logistics, Special Operations Forces (SOF), Other Government Agency (OGA), and Personnel Recovery (PR) systems. Conventional systems provide up-to-date information on personnel locations, known enemy locations, engagement locations, and messaging capabilities. Logistics BFT systems track vehicles and containers using one-way or two-way systems and are typically unclassified. SOF and OGA systems also track

personnel, but emphasize technologies that conceal SOF and OGA locations. These systems are primarily only one-way systems and operate at a classified level. PR systems provide classified tracking and messaging capabilities for people needing rescue and are commonly used by aviators.

In the US military, the most successful BFT system is the Force XXI Battle Command Brigade and Below-Blue Force Tracking (FBCB2-BFT) system [10] [11]. FBCB2-BFT is a Command and Control (C2) system that allows for electronic communication and BFT. FBCB2-BFT allows commanders to see the location of blue force vehicles, allows operators to mark reported location of enemy forces and battlefield conditions, and allows for electronic message communication [10] [11] [12].

After Operation Desert Storm in the early 1990s, the US Army recognized the need to improve their C2 capabilities. Emerging from this need, projects were developed to digitize the battlefield. In 1999, three US soldiers were captured by Serbian forces who claimed that the three had entered Yugoslav territory [2]. The US denied that the soldiers crossed into Yugoslav territory, but there was no way to actually track their movements. This led to what was known as the Balkan Digitization Initiative, a project aimed to track vehicles, to be fast-tracked. The US Army decided on utilizing a satellite-based GPS system commercially used to track vehicles in North America and integrating this system with the FBCB2 system, a ruggedized notebook touchscreen computer that could be mounted in a vehicle [2]. During the Balkan conflict, the FBCB2-BFT system was successfully deployed in theatre to track 600 vehicles all allowing for communication and tracking of vehicles positions even in areas where radios did not work [2] [11] [12].

The trial in the Balkans and the improved maturity of the FBCB2 system allowed for its formal deployment in Afghanistan and Iraq in 2002 [2] [11] [12]. In Afghanistan, the FBCB2-BFT system was changed to operate with L-band satellites allowing helicopters and land vehicles to share the same battlefield picture. In Iraq, approximately 6000 land and air vehicles were equipped with BFT. Commanders and senior leaders from the Pentagon had a common operating picture and could follow force maneuvers in near real-time [2]. FBCB2-BFT has received widespread praise from the military community and has won a number of awards for providing much improved SA [9] [11] [12].

## **1.2 Research on Blue Force Tracking**

Anecdotally, the digitization of the battlefield and the ability to track blue forces is said to have dramatically transformed the US Army's C2 capability. Several reports have documented the positive and enthusiastic responses from commanders:

“Based on my experience, I am convinced that digital battle command is the key to success in current and future conflicts. We need to embrace digital battle command and recognize its importance in the twenty-first century warfighting.”

— “LTC John W. Charlton, Commander, Task Force 1–15 Infantry, 3ID” [11].

“You are focused [with FBCB2-BFT]. You have just reduced layers of friction, and the fog of war is why units lose. This is simultaneous, real-time synchronization. It reduces the friction of war about a hundredfold.”

— “CPT Stewart James, Commander, A Company, 2nd Battalion, 69th Armor” [11].

“The single most successful C2 system fielded for Operation Iraqi Freedom was the Force XXI Battle Command Brigade and Below-Blue Force Tracking (FBCB2-BFT) system... BFT gave commanders situational understanding that was unprecedented in any other conflict in history.”

— “3rd Infantry Division (Mech)” [5].

These comments highlight the key benefit commanders found with using BFT that it improves SA by providing a common operating picture in near real-time. The improved SA allows commanders to understand the limits of their force, constantly evaluate the responsibilities and tasks of a mission, understand the costs and benefits provided by the environment at a point in time, understand the dangers in tactical circumstances, and understand the risks associated with a situation [13]. However, despite its extensive use and the accolades that BFT technology has received for improving SA, only a few empirical studies have investigated the benefit of BFT.

McGuinness and Ebbage [14] investigated the effects of digitizing the battlefield for C2, including the use of BFT for tracking blue forces. In this study, United Kingdom (UK) military participants were paired in teams, one playing a Commanding Officer (CO) role and the other an Operations Officer (OP). In a synthetic environment, they were tasked to lead their units, maintain a fix on their position, and find an enemy unit. In one mission run, the teams only had radio communication; in a second run the teams had access to a digitized system providing text-based communication, a digital map with BFT, and the ability to mark enemy position. The authors found an SA advantage for the digitized C2 with respect to participants’ confidence in their SA, but also that the COs were less confident in their SA for enemy positions with the digitized C2 system. Moreover, workload was lower for COs in the digitized C2 teams, but not for the Operations Officer (OP). While this study provided some early indication of the potential advantages of BFT and digitizing C2 information, the authors focused only on enemy SA (rather than on blue force SA) and they did not provide inferential statistical analyses of their data.

In another study, Armenis [15] examined the effect of using BFT for section commanders remotely leading fire teams. Commanders were tasked to direct remote teams using either a paper map or with a BFT system. The fire teams had to navigate to a specific location, retrieve an asset, and simultaneously guard a landing zone. When using BFT, the missions were completed faster, the commanders reported that they had better SA, and there was a reduced need for communication relative to the paper map condition.

Dreier and Birgl [12] conducted a retrospective investigation on the impact of FBCB2-BFT in theatre. They argued that while FBCB2-BFT was deemed a success, not much was known about the actual impact of BFT on accomplishing mission goals and its effect on C2. They conducted a survey of US Marine Corps veterans who had used BFT in missions in Afghanistan and Iraq. Respondents reported that BFT reduced radio communication considerably and the majority of respondents (59%) felt that BFT improved the chances of mission success. The majority of respondents did not feel that the BFT should alter the C2 command hierarchy, even though commanders at all levels would have access to a common picture. Moreover, while 46% of respondents did not think that BFT offered commanders more autonomy in making decisions, 42% of respondents did think that BFT allowed for more autonomy. The authors concluded that while it appeared that BFT increased the likelihood of mission accomplishment and reduced communication, it did not drastically affect the way C2 was conducted.

Beyond the benefits of improved SA, reduced communication, and improved chances for mission accomplishment, BFT provides the additional benefit of providing effective Combat Identification (CID) and thus preventing friendly fire [2] [8] [16] [17]. The frequency of friendly fire is extraordinary. For example, although the data is difficult to validate, one report suggests that US fratricide during World War II ranged from 2–21% of all US military deaths [2]. In the first Gulf War, 24% of all casualties were related to friendly fire [2]. Kirke [17] reports that data from the UK and the US estimate that friendly fire accounts for 10–15% of wartime casualties. Data from the UK Defence Science and Technology Laboratory (DSTL) that looked at conflicts involving western nations from 1900–2006 suggests that land-to-land battles constitute the greatest risk for friendly fire, accounting for 50% of all incidences. From a total number of 1132 land-to-land battles in this time period, 84% had an instance of friendly fire incidences [18].

In contrast, during the wars in Afghanistan and Iraq, casualties from friendly fire were surprisingly low. Only 4% of casualties were the result of friendly fire and it has been suggested that this reduction in fratricide is the direct result of having BFT [2]. Bryant and Smith [16] argue that BFT supports CID in two ways. First, BFT can be used as a cue when evaluating friend or foe. When a BFT system indicates a friendly position, the soldier can then validate that information with visual cues (e.g., uniform, weapon) to make a proper identification. Second, BFT position knowledge can shape expectations concerning the battlespace and can affect the decision thresholds used to identify an enemy target or friendly unit. Indeed, Bryant and Smith [16] compared CID judgments of dismounted soldiers using a handheld BFT, a rifle-mounted Interrogate Friend or Foe (IFF) system, or no decision aids. They found that having either IFF or BFT supported CID judgments over having no decision aids.

In the near future, BFT capability will be extended to all dismounted troops, not just vehicles. In Canada, the ISSP program is currently implementing BFT capability for individual CAF soldiers [3]. Similarly, the US Army is currently working on the next generation of BFT, called the Joint Battle Command—Platform (JBC-P) [19] [20]. JBC-P builds on FBCB2, and FBCB2 Joint Capabilities Release (JCR) [21]. JBC-P will put BFT on handheld devices that will be distributed down to the lowest military echelons. JBC-P intends to improve CID, better situation awareness for moving targets and more accurate position locations for friendly units [20]. Ideally, by providing individual ground troops with the same near real-time picture of the battlefield as upper-echelon commanders, soldiers will have more complete situation awareness and access to real-time information of team member and other forces, which will allow for better synchronization of team activities.

However, it is unclear how dismounted soldiers will use and benefit from BFT technology. Arguably, the tactical and user requirements for BFT are different for dismounted troops compared to the operational requirements for commanders who lead troops from a command post. One way that these two groups may experience the usefulness of BFT differently is in the inherent inaccuracy of GPS. At higher levels of command, which considers vast areas at brigade or company level operations, current levels of BFT signal accuracy appear to be sufficient [11] [13]. However, for dismounted troops who are more concerned with tasks in their immediate surroundings, it is unclear whether BFT inaccuracies can properly support their tasks.

### **1.3 BFT Signal Accuracy**

The primary method that BFT systems use to track assets and people is through GPS [10] [11]. Since GPS became fully operational as a public service in 1995, it has become an essential for tracking individuals and assets for a variety of industries and applications. GPS works by providing targets

(whether a person or an asset) with a GPS receiver. The receiver listens for signals broadcast from satellites and based on the time each of these signals reach the receiver and the time the signals are sent, the position of that target can be calculated. This process is not always accurate. GPS accuracy depends on multiple factors, including GPS receiver quality, satellite positions, atmospheric conditions, multipath signals from nearby structures, target movement, and whether the target is indoors or outdoors [22] [23] [24] [25] [26]. With commercial GPS systems, spatial error ranges from over a metre to tens of metres [25]. Zhou et al. [26] reported that under relatively ideal conditions (clear skies, light foliage and canopy), stand-alone GPS resulted in averaged Root Mean Square (RMS) errors of approximately 2–3 metres. However, when their GPS was tested close to buildings, GPS errors were large and variable, ranging from 2–30 metres. Moreover, vertical GPS error is greater than for latitude or longitude position. Wing and Frank [27] tested a number of mapping-grade GPS systems and found the average vertical error was between 3–5 metres. Even though a GPS signal might accurately reflect a target's latitude and longitude, it might not be possible to determine whether a target is on the ground or a rooftop.

For many tasks, despite the inaccuracy of GPS, the localization of the target sufficiently provides the user with the information needed to accomplish their goals. For instance, for FBCB2-BFT, the update rate of the BFT signals was every five minutes [5] [8] and thus commanders would not have accurate blue SA if assets move within the five-minute interval. Nevertheless, higher-level commanders reported that the five-minute latency of FBCB2-BFT still provided sufficient SA of their assets and that they could adequately track force movement [5].

For other tasks—including those performed by dismounted infantry—even a small amount of error may be problematic. For example, Bryant and Smith [28] had participants play the role of an infantry soldier in a simulated environment. Their task was to detect, identify and shoot “enemy” bots moving in their field of view. The enemy bots could be identified with visual cues such as their uniform and their weapon. In one condition, the participants had no decision support. In a second condition, they were given a BFT device that accurately tracked friendly force positions. In a third condition, participants were warned that the BFT would have a 10-second delay. In a fourth condition, participants were not warned that their BFT had a 10-second delay. Their results suggested that adding a 10-second delay to the BFT information, regardless of whether participants were warned of the delay, resulted in poorer performance. In particular, participants in these conditions exhibited similar false alarm rates (i.e., shooting a friendly bot) as in the no decision support condition.

In another study, Benford et al. [29] highlighted the varied ways users experience GPS inaccuracies. In this study, live participant players (called runners) and online participants played a game of mixed reality tag. Runners were given a handheld computer with GPS receivers and had to navigate through real city streets to try to catch online players. Online players had a virtual character representing them and walked around a model of the city from a desktop computer trying to avoid runners. Through the handheld device, runners could see the location of online players and had to try to get within five metres of online players to “catch” them.

Runners continually noticed GPS problems. Occasionally, they could not get a GPS fix when navigating between buildings. They also had to deal with positional errors when the GPS could not accurately track their location. When their GPS position was inactive, they resorted to verbal communication through the radio to broadcast their positions. They also tried to back track their steps to re-establish a signal. In contrast, online players were largely unaware of GPS errors. They had no awareness of the true locations of runners, so they acted according to the GPS information given to them. When online players did notice

a runner's GPS signal disappear on the screen, they treated this error as part of the game where runners would hide. While this study was conducted in the context of a game, it demonstrates how different users' groups can experience GPS errors in dissimilar ways. For online players, who lacked knowledge of actual runner positions, the GPS worked sufficiently for them to use the information (even when incorrect). For the runners, who were being tracked and had awareness of their own positions, they were continually trying to compensate for the GPS errors and found it difficult to perform their task as a result.

Dismounted soldiers with BFT may find themselves in a similar position as the runners in the Benford et al. study. Unlike commanders in a command post, dismounted troops likely have more precise tracking requirements to perform their task. While military BFTs currently available provides faster position, location and information refresh rates than those used in Iraq and Afghanistan [19] [20] [21], any inaccurate BFT information may actually hinder a dismounted soldier's ability to perform their task. It is unclear whether the current levels of signal accuracy for BFT are sufficient and whether inaccuracies could compromise mission performance. Because BFT can shape a soldier's mental representation of the battlefield [28], tracking inaccuracies of assets and people could lead to spatial navigation problems, errors in blue force identification, loss of mission SA, fratricide, and mission failure.

In this report, we describe two experiments that investigate whether signal inaccuracy in BFT localization for dismounted infantry soldiers affects their SA, workload and mission performance. In Experiment 1, we investigated the effect of BFT signal inaccuracy on dismounted soldier performance by having soldiers conduct a simulated environment under different levels of BFT signal accuracy. Participants conducted a mission using either a digital map with no BFT, a map with accurate BFT, or a map with inaccurate BFT. In Experiment 2, we expanded on Experiment 1 by employing a more complex and realistic mission (a hasty attack). We also examined issues with BFT signal inaccuracy when using simulated head-mounted AR technology for display BFT to dismounted soldiers.

## 2 Experiment 1<sup>1</sup>

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In Experiment 1, each participant played the role of a *section commander* attempting to locate and support another section in contact with enemy combatants. There were two key *Encounters* that required the participant to make a judgment on whether a unit was friendly or not. In Encounter 1, the section is fired upon by a lone sentry at a guard post and the participant had to decide whether to return fire. In Encounter 2, two groups of combatants are engaged in a fire fight, and the participant must decide which side to support. Participants performed these tasks with and without a BFT system. There were three BFT conditions: No BFT, Accurate BFT, and Inaccurate BFT. Later, the participant had to indicate the location of various entities in an Encounter. Multiple dependent measures were recorded and can be broadly classified into five categories: (1) mission performance, (2) BFT / map interactions, (3) communication, (4) subjective mental workload, and (5) retrospective spatial awareness.

### 2.1 Method

#### 2.1.1 Participants

Thirty-six male infantry soldiers from the CAF participated in Experiment 1. Participants ranged from 22–39 years with an average of 27.24 ( $SD = 4.75$ ). They had an average of 6.35 years in the military ( $SD = 3.94$ ), and 7.88 months ( $SD = 4.66$ ) of experience in theatre. No participants had experience with using BFT in theatre or any other training using BFT. Participants provided informed consent prior to the study.

#### 2.1.2 Apparatus

The experiment was conducted at DRDC – Toronto Research Centre in a dedicated room with computer workstations. Each workstation was separated from other workstations by office partitions. Each workstation had an ASUS Intel Core i7 desktop computer, running Windows 7 on a 56 cm (22 in.) Philips Brilliance 220BW monitor. Participants wore Plantronics headsets that presented auditory sound effects during the simulation. The monitor settings and the sound levels were matched across computers. Participants were given a pad of paper and a pen to take notes (e.g., for briefing orders).

The simulation was run in Virtual Battle Space 2 (VBS2) [31]. VBS2 is a military training and experimentation package based on commercial video game technology. It allows participants to play first-person military-based land, sea, and air missions in a high-fidelity virtual environment. VBS2 contains a large volume of libraries with realistic models of CAF equipment and assets. It allows experimenters to develop their own mission scenarios and to collect human performance data on missions.

Four similar simulated scenarios were customized using VBS2 (described in further detail in 2.1.4). While running in each of the scenarios, the participant could press the shift key at any time to bring up a two-dimensional north-up map, centred on the participant's position. This map was also developed in

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<sup>1</sup> Experiment 1 was published in [30]. The data in the current report were reanalyzed and we applied non-parametric analyses. In the previous publication, we employed a parametric analysis, hence there are slight differences in the findings.

VBS2. This map indicated the participant's position and/or other blue force soldiers, depending on the experimental condition (see Section 2.1.3.1). The map could be zoomed in and out to allow the participant to adjust the scale of the map. The participant could also pan the map to see adjacent areas without changing the map's scale.

### **2.1.3 Design**

#### **2.1.3.1 Independent Variables**

Experiment 1 used a within-subjects design with three levels of BFT:

1. In the *No BFT condition*, participants were provided with a 2D digital map of their area of operation and they were able to read text-based messages from their platoon (to simulate text-based communications). The map was centred on the participant's character (the section commander).
2. In the *Accurate BFT condition*, participants were provided with a 2D digital map of their area of operation that also displayed blue force positions. The signal accuracy of the BFT was 100% accurate. Otherwise, the condition was identical to the No BFT condition.
3. The *Inaccurate BFT condition* was identical to the Accurate BFT condition except that the BFT had positional tracking error. For each BFT representation of a blue force soldier, there was a randomly selected linear error (between 0–10 metres) and angular error (between 0–359°) from the true position.<sup>2</sup> The error was fixed at the beginning of each mission and did not change during the simulated mission. While in reality, GPS error is not fixed, it also does not fluctuate dramatically from one moment to the next. The primary sources of GPS inaccuracies are based on atmospheric conditions and the environmental conditions of the receiver (e.g., multipath and tree canopy) [22] [23] [24] [25] [26], both of which are relatively constant over short durations. Thus, the simulated error is perceptually similar to what someone might experience in reality.

#### **2.1.3.2 Dependent Variables**

The five categories of dependent variables are fully described in Table 1. For the categories Mission Performance, BFT / Map Interaction and Retrospective Spatial Awareness, several lower level measures were collected to gain an overall indication of the construct. Mission Performance was defined by the time required to complete the mission, the time required for participants to identify and fire upon the enemy during Encounters 1 and 2, and metrics on whether they fired upon enemy or friendly forces.

The BFT / Map Interactions measures capture the participant's use of their BFT or map device (e.g., panning and zooming the map). Presumably, with BFT, because more information is available, the participant would use their device more to obtain battlefield SA. Text communications captured the frequency that the participant used their messaging system to contact their commander for information. Workload was captured after completing each scenario using the National Aeronautics and Space Administration—Task Load Index (NASA-TLX) [33]. The final dependent measure category, Retrospective Spatial Awareness, measured the participant's ability to recall the blue force positions from completed mission.

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<sup>2</sup> An error up to 10 metres was chosen because it was in the range of the minimum horizontal accuracy in unobstructed terrain for ISSP [32].

**Table 1:** *A list of the dependent variables for Experiment 1.*

<b>Mission Performance</b>	
Time to Complete(s)	Elapsed time from mission onset (key press) to mission's end (time when all enemy combatants are killed).
Time to Complete(s) (Encounter 1)	Elapsed time from time the player assumes control of simulated character to when the sentry is hit or surrenders.
Time to Fire(s)	Elapsed time from onset of Encounter 2 (which began once the participant's character reached a specific point in the simulation) to the time when the participant first fires their weapon.
Hits	Number of shots that hit an enemy character.
False Alarm	Number of shots that were fired at a friendly soldier.
<b>BFT / Map Interactions</b>	
BFT / Map Activation	Frequency that Map/BFT is activated.
Panning	Frequency that Map/BFT is panned.
Zooming In	Frequency that Map/BFT is zoomed in.
Zooming Out	Frequency that Map/BFT is zoomed out.
<b>Text Communication</b>	Number of times the participant activates the text messaging.
<b>Workload</b>	Participant's aggregate score on the NASA—Task Load Index (TLX).
<b>Retrospective Spatial Awareness</b>	
Encounter 1—Locate Sentry	Participant's accuracy in locating the sentry.
Encounter 2—Locate Self	Participant's accuracy in locating themselves.
Encounter 2—Locate Friendly and Enemy Forces	Participant's accuracy in locating other blue and enemy forces.

#### **2.1.4 Mission Scenario**

The simulated mission was set in an urban environment during daytime conditions with no civilian or automobile traffic present. The mission begins with the participant receiving a brief on the screen. The brief states that their mission is to support another blue force section under fire from enemy forces. The participant is instructed to lead their section through urban streets to the area of the engagement. Once

there, they need to identify the blue forces, and engage enemy attackers. The participant had to navigate through the urban area using a digital map or BFT device (dependent upon experimental condition). Once the participant finished reading the mission brief, they pressed a “Start” button to commence the mission.

The mission began with a seven second animated prelude in which the participant’s section is walking north on an urban street. During this prelude, the participant did not have control over their simulated character. At the end of the prelude, the section is fired upon by a sentry at a guard post (Encounter 1). The team takes cover and the participant’s character is crouched behind a bus shelter. A text message from the section Second in Command (2IC) is presented on the screen stating that the shots came from the guard post and that the participant needs to make a positive identification before firing. At this point, the participant is able to respond and control the character. On half the missions, the sentry was a blue force soldier who mistakenly fires upon the section. For the other half, the sentry was an enemy soldier. The participant had to decide whether to return fire.

Participants had two ways of determining the sentry’s identity, either through their BFT (in the BFT conditions) or through the text-based communication to their Platoon Commander (PC) to determine whether the sentry was friendly (the sentry’s appearance did not indicate his identity). If the participant used their BFT, they would see a blue dot representing at the sentry’s position if the sentry was friendly. If the blue dot was not present, it would indicate that the sentry was not friendly.

In the Inaccurate BFT condition, the blue dot is present and still provides the information necessary for the participant to make a decision to fire or not. However, the position of the dot would not correspond with actual position of the sentry. We wanted to test whether this positional error would contribute to any confusion and thus delays in the decision to fire or not.

If the participant decided to call their PC to verify the identity, they had to press the tilde key to bring up the text-based messaging and select the option to ask for the sentry’s identity. After 10 seconds, the PC responds with sentry’s identity (friendly or not friendly). If the sentry was friendly, the PC responds that the sentry is friendly and the sentry raises his hands indicating safe passage. If the sentry was not friendly, the participant was told that they could engage the sentry. The participant then has to fire and kill the sentry.

The 10 second-limit for the PC’s response was intentional to restrict the length of the response. We note that 10 seconds is unrealistically fast to receive a response from higher command. We consulted with two Subject Matter Experts (SMEs) on how long it would take to make a positive ID through radio. Both SMEs said a very fast response would be around 15–30 minutes. Radio communication to maintain SA on blue forces is generally effortful and time consuming [34]. Thus, we are confident that the 10 second response we applied for using radio or text in this scenario is unrealistically biased against using BFT. Thus, any benefit we observe from using BFT would be relatively limited to the benefit in time savings in a real combat situation.

These two tasks represent the current and potentially future ways to acquire the identification of an unknown person. As Dreier and Birgl [12] argue, BFT provides a common operating picture to all soldiers, and as a result, it allows soldiers at lower levels of command to take actions without relying on higher command thereby reducing the information flow within a C2 hierarchy. This comparison allows us to test this possibility.

After Encounter 1, the participant leads the section to the engagement involving the other blue force (Encounter 2). As the section arrives close to the destination, gun fire can be heard and seen being exchanged between two groups of combatants in buildings across the street from one another (Figure 1). On half the missions, the blue force was in the building to the north; on the other half, the blue force was in the building to the south. Again, the appearance of both groups was non-diagnostic, so the participant could not visually judge which group was friendly.



**Figure 1:** A screenshot of participant's character as it approaches Encounter 2 (left) and an example of the BFT showing friendly forces situated in the north building (right).

The participant had to decide which building the enemy was in, using the text-based messaging or through the BFT (if available). Having decided, the participant had to contact their PC through the text messaging to specify the group that they were engaging. Then the participant fired upon the enemy. The mission ended when all enemy combatants were killed. The duration of each mission (both Encounters) was approximately 5–10 minutes.

The task could be accomplished in all three conditions. In the Inaccurate BFT condition, the BFT displayed the blue forces in the correct building, but there were errors in the actual positions of the soldiers. In this respect, it did not differ from the Accurate BFT for making the decision to fire. However, as in Encounter 1, we were interested in whether the positional error might confuse the participant and result in a delay in the participant's time to complete the mission.

## 2.1.5 Procedure

Each participant was seated at a workstation, participants were run individually or as part of a group. In the latter case, the workstation partitions served to separate the participants and reduce the likelihood of their interaction. The experimenter gave a verbal description of VBS2, the BFT system for each condition, and a description of the mission. Participants received training on how to play VBS2. These included instructions on how to: navigate the character, control the field of view, aim and fire the weapon, and use the text messaging, the map, or simulated BFT device. Participants ran through two practice missions.

Subsequently, participants performed six experimental missions, two missions for each of the three BFT conditions. The order of the conditions was counterbalanced. Within each condition, the two missions differed in whether the sentry in Encounter 1 was friendly or not and whether the friendly forces were on the north or south building in Encounter 2. The two missions within each condition were also counterbalanced. Before each condition, the participant was presented with five images illustrating the BFT's signal accuracy. Each of the five images displayed two near-identical maps. One map showed

“ground truth” positions of the participant and other blue forces. The second map showed how these positions might appear on their BFT device. In the No BFT condition, the participant saw similar pictures but it only showed the map with the participant’s own location. These images provided participants with examples of how their BFT device would appear during the experiment. After viewing each image, the participant initiated the mission on the computer. Participant data were tracked and logged during each mission.

After each trial, participants completed three multiple-choice questions to measure the participant’s retrospective spatial awareness of the battlefield. Each question presented four identical maps with different representations of friendly and enemy positions, with only one map accurately depicting the geospatial positions of people. The other three maps had the positions randomly jittered. This random jitter was independent of the process to create the error in the Inaccurate BFT condition. Participants were asked to select the map that most accurately represented the location of friendly and enemy positions. Question 1 asked about the sentry during Encounter 1; Question 2 asked participants to locate their own position at the end of the mission; Question 3 asked participants to select the map that accurately showed blue force positions. Subsequently, participants completed the NASA—Task Load Index (TLX) to assess subjective workload [33]. After completing the NASA-TLX, participants started the next mission. The process was repeated until all six trials were completed. The entire session was approximately 1.5 hours.

## 2.2 Results

Due to an error while running the study, the workload measures were only collected from 28 participants. The rest of the measures had full data sets from 36 participants. The data were first screened for outliers and normality. Using Fisher’s measure of skewness ( $Y_1$ ), thirteen measures were moderately ( $Y_1 > |.76|$ ) or extremely skewed ( $Y_1 > |2.25|$ ) [35]. Therefore, we applied a cube root transformation to all of the data. After transforming the data, eight of the measures still had moderate to extreme degrees of skewness. While Analyses of Variance (ANOVAs) are generally robust to violations of normality, we found that the results of the parametric test (repeated-measures ANOVA) differed from the non-parametric test (Friedman Test). As a result, we report the results of the non-parametric Friedman test.

Friedman’s tests used an alpha level of .05 for each dependent measure. Planned comparisons were conducted using a Wilcoxon signed rank test. A Bonferroni correction was applied to control the familywise error rate. Table 2 shows the means and Standard Errors (SEs) of each dependent measure in each of the conditions. Only significant results are discussed.

There was a significant effect of Time to Fire. The Wilcoxon signed ranks test suggested that the Accurate BFT condition was marginally faster than the No BFT condition,  $Z = -2.0$ ,  $p = .046$ . Similarly, the Inaccurate BFT condition was also marginally faster at firing at the enemy relative to the No BFT condition,  $Z = -1.84$ ,  $p = .066$ . No other comparisons for Time to Fire were significant.

Employing BFT also altered the way participants interacted with their map device as suggested by the significant effects of map activation, map panning and zooming out. Planned comparisons on map activation suggested that participants activated their maps more frequently in both the Accurate BFT condition,  $Z = -2.4$ ,  $p = .016$ , and the Inaccurate BFT condition,  $Z = -2.59$ ,  $p = .01$ , relative to the No BFT condition. There was no significant difference between the Accurate and Inaccurate BFT conditions on map activation.

Participants also panned their map more frequently when they had BFT. There were significantly more instances of panning when using the Accurate BFT relative to the No BFT condition,  $Z = -2.76$ ,  $p = .006$ . There was also marginally more panning for the Inaccurate BFT condition relative to the No BFT condition,  $Z = -2.14$ ,  $p = .032$ . There was no significant difference in panning between the two BFT conditions.

**Table 2:** Means (Ms) and Standard Errors (SEs) for each dependent measure in the No BFT, Inaccurate BFT and Accurate BFT conditions.

		No BFT		Inaccurate BFT		Accurate BFT	
		<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Mission Performance							
	Time to Complete Mission(s)	229.78	14.64	209.25	12.22	197.03	12.73
	Time to Complete Encounter 1(s)	25.46	1.48	25.90	1.87	27.13	3.00
	Time to Fire Encounter 2(s)	** 52.18	3.08	50.28	4.62	44.46	4.25
	Hits	10.22	0.48	10.17	0.41	10.58	0.35
	False Alarms	0.52	0.20	0.78	0.31	0.42	0.21
BFT / Map Interactions							
	BFT / Map Activation	** 2.07	0.30	3.42	0.53	3.47	0.50
	Panning	*** 1.88	0.48	3.08	0.58	3.31	0.49
	Zooming In	3.90	0.72	2.36	0.50	2.19	0.55
	Zooming Out	* 1.94	0.49	5.33	0.80	4.89	1.30
Text Communication (frequency)	*	2.88	0.28	2.32	0.25	2.42	0.31
Mental Workload		32.23	3.12	24.94	2.01	25.19	3.58
Geopositional Awareness							
	Encounter 1	0.88	0.05	0.81	0.06	0.83	0.04
	Encounter 2—Self	0.71	0.05	0.67	0.06	0.57	0.06
	Encounter 2—Friendly Forces	* 0.93	0.03	0.88	0.05	0.96	0.03
		* (p < .05)    ** (p < .01)    *** (p < .001)					

Similarly, there was a significant effect for zooming out when using BFT. Participants using the Inaccurate BFT zoomed their maps out more frequently relative to the No BFT condition,  $Z = -3.24$ ,  $p = .001$ . Again, there were no significant differences between the Accurate and Inaccurate BFT conditions. Thus, when using BFT, participants panned and zoomed out their maps more than when they did not have BFT, presumably to gather SA on blue forces not in their immediate vicinity.

Lastly, there was a significant effect of text messaging the PC. Relative to the No BFT condition, text messaging was marginally less frequent in both the Accurate BFT condition,  $Z = -1.85$ ,  $p = .064$ , and the Inaccurate BFT condition,  $Z = -1.96$ ,  $p = .05$ . Again, the effect of signal accuracy was not significant between the Accurate and Inaccurate BFT conditions.

## 2.3 Discussion

Experiment 1 suggests mixed results for using BFT for dismounted soldiers. While there were some benefits for using BFT, there were no differences on any measures related to BFT signal accuracy. The findings suggest that using BFT resulted in faster times to engage the enemy; however this was the only significant effect for mission performance. When using BFT, participants also tend to use the map more and did more panning and zooming (specifically zooming out) likely to gather SA on other blue forces. Participants also relied less frequently on their PC to give them accurate force position data. Finally, there was no effect on workload with using BFT. These findings are similar from previously reported work on BFT [15] which found no difference in workload but reported faster mission completion times and less radio communication when using BFT.

The complementary findings between the two studies are promising given that Armenis [15] ran a complex field experiment versus our simulated laboratory study. The two studies also differed in that the participants in [15] were section level commanders who were remotely directing live troops through their task using BFT. In contrast, our study looked at commanders who were alongside their dismounted soldiers, using BFT to navigate and engage an enemy force. Thus, the demands of the task were quite different. Second, Armenis [15] also ran a field study using confederates to play the role of soldiers whereas in the present study, the mission was completely in simulation. Thus, despite the differences in the way the studies were conducted and the demands placed on the participants, the general findings are consistent suggesting that BFT allows participants to gather additional SA on friendly forces, that it has mission performance benefits, but does not unduly task workload.

The null effect of BFT signal accuracy was somewhat surprising. It was expected that information that is less accurate would likely result in poorer performance due to difficulty cognitively translating the discrepancies between the display and the actual positions of soldiers. However, the fidelity of the blue force data in both conditions was likely sufficient for the task that we provided. In this task, the participant could use the blue force data to help them with (a) navigating to the other blue force and, (b) making the determination of which set of combatants to engage, the ones on the north building or the ones in the south building. In both of these tasks, the fidelity does not need to be very precise and participants could simply use the centre of mass of the blue dots to support their situation awareness. Thus, the signal accuracy of blue force data only needs to be highly accurate for tasks that require high levels of positional precision.

The finding that participants were doing more panning and zooming out with the map with their blue force tracker suggests that they were using the device to gather SA. By panning and zooming out their map to their destination, the participants were presumably better able to navigate to support the other blue force and quickly decide which building they were in. We expected that this behaviour would result in faster decision times and faster mission completion times, relative to the No BFT condition. While we did not find faster mission completion times, participants did engage enemy combatants faster when they had BFT.

In sum, Experiment 1 found some benefit of using blue force tracking. Participants used BFT to gather SA on friendly force locations. This resulted in faster engagement times and less dependency on text communications. There were no differences between Accurate and Inaccurate BFT. For the most part, we attribute the null findings to the constrained nature and simplicity of the task we chose in Experiment 1.

In Experiment 2, we attempted to address some of the limitations of Experiment 1. First, the experimental task provided in Experiment 1 may not have adequately tested the signal inaccuracy of BFT since the participants did not require high accuracy to accomplish the goals of the task. Second, the maps on handheld BFT devices obscure positional errors if users do not zoom to a scale where the error is visibly pronounced. Last, the scenario we provided for the participants was too artificial and did not simulate a typical contact situation for CAF soldiers. Hence, for Experiment 2, we consulted with two SMEs (former CAF Army combat engineers from QTAC Inc.) to help guide the development of scenarios.

The SMEs suggested that BFT is unlikely to be used as a navigation tool by dismounted soldiers (as we did in Experiment 1) nor is it primarily a combat identification tool. Rather, BFT is primarily used to gather real-time SA on soldiers' positions in order to interpret the battlespace and obtain a more accurate situation assessment [7]. After much consultation with our SMEs, we decided to use a hasty attack scenario as the basis of our scenarios for Experiment 2.

A hasty attack is a recognized attack within Canadian military doctrine and is one of the most common infantry attacks using simple and quick planning and coordination [36]. The hasty attack scenario allowed us to provide participants with a realistic scenario for an infantry commander who can use their BFT to monitor the attack. It also allows us to better address the first limitation because during a hasty attack, it is important for assault teams to be ready at their attack positions before firing commences. The attack can result in fratricide situations if the firebase neglects to shift fire appropriately or if assault teams are in the incorrect position.

In addition, Experiment 2 examined whether dismounted soldiers could benefit from viewing BFT information through simulated head-mounted AR. Future generations of BFT will likely see BFT positional data presented to a soldier's forward view, using a Head-Mounted Display (HMD) with AR [5] [37] [38] [39] [40]. In head-mounted AR systems, dynamic real-time positions of friendly force are presented in the user's field of view using computer-generated icons or symbols that are directly superimposed over blue force individuals. BFT HMD-AR systems offer a great deal of promise by providing soldiers with intuitive and immediate information on friendly force positions and movements.

However, errors in displaying positions in AR are much more salient because they appear directly in the forward view of the soldier wearing the device. Any blue force visualization would have to be directly coupled with the real-time movements of individual blue forces within the soldier's view. Unlike a handheld device then, even errors of a metre or two might appear to be malfunctioning and unusable thus resulting in difficulties gathering SA and using the BFT information during a mission. Currently, the US Army is prototyping and testing an AR-based BFT system called ARC4 as part of the US Army's Nett Warrior program [5]. AR systems for military applications and in particular for dismounted soldiers, has been a common theme in military research and is expected to be one of the technologies that future soldiers will be equipped with to provide them with real-time information about their surrounding battlefield [5] [37] [38] [39] [40].

### 3 Experiment 2

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The primary focus of Experiment 2 was to investigate whether BFT presented through AR would provide dismounted soldiers any benefit with respect to mission performance and battlefield awareness. Moreover, because position localization and tracking issues are critical for AR systems, we wanted to investigate to what extent inaccurate localization and tracking would have on soldier performance when using AR BFT.

AR systems allow users to interact with the real world while simultaneously interacting with virtual world objects that are superimposed onto real-world objects or blended with real-world objects [41]. AR typically has three key characteristics: (a) it combines the virtual world and the real world, (b) it is interactive and in real-time, and (c) the virtual objects are presented in three dimensions [41]. AR research was first pioneered in the 1960s at Harvard University and the University of Utah. In the 1970s and 1980s, a small number of research laboratories continued this line of research, including the U.S. Air Force's Armstrong Laboratory and NASA Ames Research Center. It was not until the 1990s that the term "Augmented Reality" was coined and AR emerged into its own field of research. Today, with games like Pokémon Go™ and commercial products like Microsoft's HoloLens™ and the Magic Leap™, AR is becoming more commonplace to the everyday user. AR also has many industrial applications like maintenance, manufacturing, tourism, medicine and the military [42]. Potential military applications for AR include support for equipment maintenance, medical applications, training and simulating combat, presenting aerial surveillance data to ground soldiers, navigational support, and blue force tracking [8] [39].

However, there are still some significant challenges for AR before it can be a ubiquitous and useful technology. Azuma [41] identified four key issues for AR: (a) precise tracking to support pixel-accurate registration across many varying environments (e.g., indoor, outdoor, inclement weather); (b) displays that provide a wide-field of view and minimize external ambient light; (c) interfaces that allow control of AR objects without traditional peripheral devices, and finally (d) a semantic understanding of real-world objects across multiple environments. Because dismounted soldiers operate in a wide variety of land environments and often under very unfavourable conditions, AR-based BFT would have to overcome all four of these issues to be useful.

Therefore, future BFT display systems using AR will require even greater localization and tracking precision. The spatial and temporal precision of AR symbology needs to be directly coupled to the real-time movements of the people and objects around the user [43]. BFT in AR would require the ability to perform 360° pixel accurate localization and tracking of blue force individuals. When BFT is presented in the soldier's field of view, as it is with AR, the inaccuracies of the BFT data becomes much more salient, particularly at close distances. The current errors that are experienced with common GPS of 2–30 metres would likely be rejected as the blue force symbology would appear nowhere near the soldier at close distances. The temporal lag of updating information would also have to occur in real-time. Even a few seconds of delay may cause significant lag for the user as people move within the user's field of view. In addition, whereas vertical GPS error is not apparent when looking at the 2D aerial map, in AR, because GPS information is being displayed in the soldier's forward view, vertical errors in GPS signals become evident. Therefore it would be expected that localization accuracy issues with presenting BFT information will be much more problematic for AR displays.

In the present study, we had participants conduct simulated hasty attacks using different variations of AR visualizations and compared them against a traditional 2D map with BFT, or with No BFT at all. In our hasty attack simulation, the participant leads the firebase in charge of suppressing the enemy, while two assault teams flank the enemy from the right or the left. This type of attack requires the firebase commander to have high SA of the assault teams' position in order to properly initiate the attack and also not to accidentally fire upon your own forces. During each attack, unexpected events could occur that could jeopardize the attack plan. The participants' task was to maintain SA on the assault teams, the enemy, the environment and the time. If an unexpected event occurred, they had to report it as quickly as possible. Last, they had to decide whether they should continue with the attack or withdraw the attack.

The map and BFT displays are described in detail in Section 3.1.4. There were four main BFT display conditions: (a) BFT Map (b) AR-Box (c) AR-Dots (d) AR-Ribbon. Each of these conditions was also divided into Accurate and Inaccurate BFT conditions. There was also a control No BFT condition, for a total of nine conditions. In the BFT Map, the display used was identical to the one described in Experiment 1. In the AR-Ribbon display, the BFT symbology was presented along a graphical bearing ribbon running along the top of the participant's forward view. In the BFT Map and AR-Ribbon displays, the blue force soldiers' location and movements are less tightly coupled to the symbology. In the AR-Box display, blue boxes were superimposed over blue force soldiers. In the AR-Dots display, a blue dot was presented over the soldier's head. In both of these conditions, the symbology was tightly coupled to the location and the movements of each blue force soldier. As a result, when the BFT is inaccurate, it was more apparent in the AR-Box and AR-Dots conditions versus the BFT Map and AR-Ribbon conditions.

We hypothesized that when conducting missions with BFT, participants would make faster and more accurate decisions regarding their attack; BFT-enabled missions would also allow faster and more accurate event detection relative to the No BFT condition. Moreover, with BFT, we hypothesized that participants have better geo-spatial memory of their troops and more confidence in their memory. We expected that when using AR versions of BFT, participants would perform better than when using a 2D map version of BFT. Unlike Experiment 1, where we found no effect of signal accuracy, the task we presented in Experiment 2 was more complex and required better coordination with other blue force teams. In addition, in AR, the signal inaccuracy in BFT is much more apparent. As such, we hypothesized that the accurate BFT conditions would result in better performance than the inaccurate BFT conditions.

## **3.1 Method**

### **3.1.1 Participants**

In total, thirty-nine Canadian Armed Forces (CAF) soldiers (38 males, 1 female) participated. The data for three participants were omitted due to complications with the data for a total of thirty-six participants. Participants were all infantry soldiers or combat engineers and all participants had the rank of Master Corporal (MCpl), Sergeant (Sgt), or Second Lieutenant (2Lt). The participants in these ranks were chosen because of their experience and training in leading section sized teams. Typically, a 2Lt would not have this experience, but our particular 2Lt participants all had experience leading combat teams. Because the CAF does not currently deploy individual BFT systems, none of the participants had experience using BFT in theatre. However, some participants have been involved in training or trials (particularly with the US Army) where BFT was available for other units.

### **3.1.2 Apparatus**

The experiment was conducted in a dedicated room at Defence Research and Development Canada – Toronto Research Centre. Participants were run in groups. Participants were seated at individual workstations with an ASUS Intel Core i7 desktop computer running Windows 7 using a 22” Phillips Brilliance 220BW monitor. VBS2 was used to run the simulation, present the stimuli, and record participant behaviours. Participants donned Plantronics headsets during the experiment. The monitor settings and the sound levels were all matched for each of the computers. A pad of paper and a pen were provided to allow participants to take notes about their briefing orders.

### **3.1.3 Design**

A two-way within-subjects design was used with BFT signal accuracy (2) and BFT type (4) as independent variables. The conditions are described in more detail in the Stimuli Section. An additional condition with No BFT was also included for a total of nine conditions. Each participant performed all nine conditions once.

### **3.1.4 Stimuli**

There were two levels of BFT signal accuracy. In the accurate conditions, the BFT was always 100% accurate in presenting the spatial locations of friendly forces. In the inaccurate conditions, the BFT information always had some error associated with it. For each friendly soldier, their BFT signal was presented with 0–10 metres of error in any direction (similar to Experiment 1). Both levels of signal accuracy were crossed with four levels of interface type corresponding to the four ways to visualize BFT information. These four BFT conditions and the No BFT condition are described in more detail below.

#### **3.1.4.1 No BFT**

In the No BFT condition, the participant is given a digital 2D map. Participants could enable and disable the map by pressing the “~” key. A blue dot is shown to represent the participant’s current position, but it does not provide any friendly soldier positions. The map could be zoomed using the mouse’s scroll wheel and panned by press and holding the right mouse button and moving the mouse. With no BFT at all, the participant must constantly try to maintain visual contact with the enemy and other friendly forces in order to have good SA. An example is shown in Figure 2. Note that when the map is activated, it blocks the forward view of the participant. This was done to simulate looking down or away from the forward view as would be necessary on a real handheld device. In this condition, it was difficult maintain SA on blue forces due to the nighttime conditions and the soldiers hiding in the tree line. This is realistic as infantry soldiers use nighttime and tree lines to remain inconspicuous to the enemy. Despite this, the task is still achievable without a BFT by maintaining visual contact through the rifle’s scope which was accessible in all conditions.



*Figure 2: An example of the No BFT condition.*

### 3.1.4.2 BFT Map

In this condition, participants were given a 2D digital map of the attack area. The map itself was identical to the No BFT condition. However, each friendly soldier's position was represented as an individual blue dot on the map. When the BFT was accurate, the blue dots correctly represented the spatial location of each friendly force soldier (Figure 3, top row, left column). When the BFT was inaccurate, the blue dots had some error in the spatial accuracy of each soldier's location (Figure 3, top row, right column). Note that there are several advantages with this type of display. First, vertical error is obscured in the BFT map condition. Second, the spatial error is less of a concern when the map is zoomed out. Third, when the BFT is disabled, the participant is less distracted with information in their forward view.

### 3.1.4.3 AR-Boxes

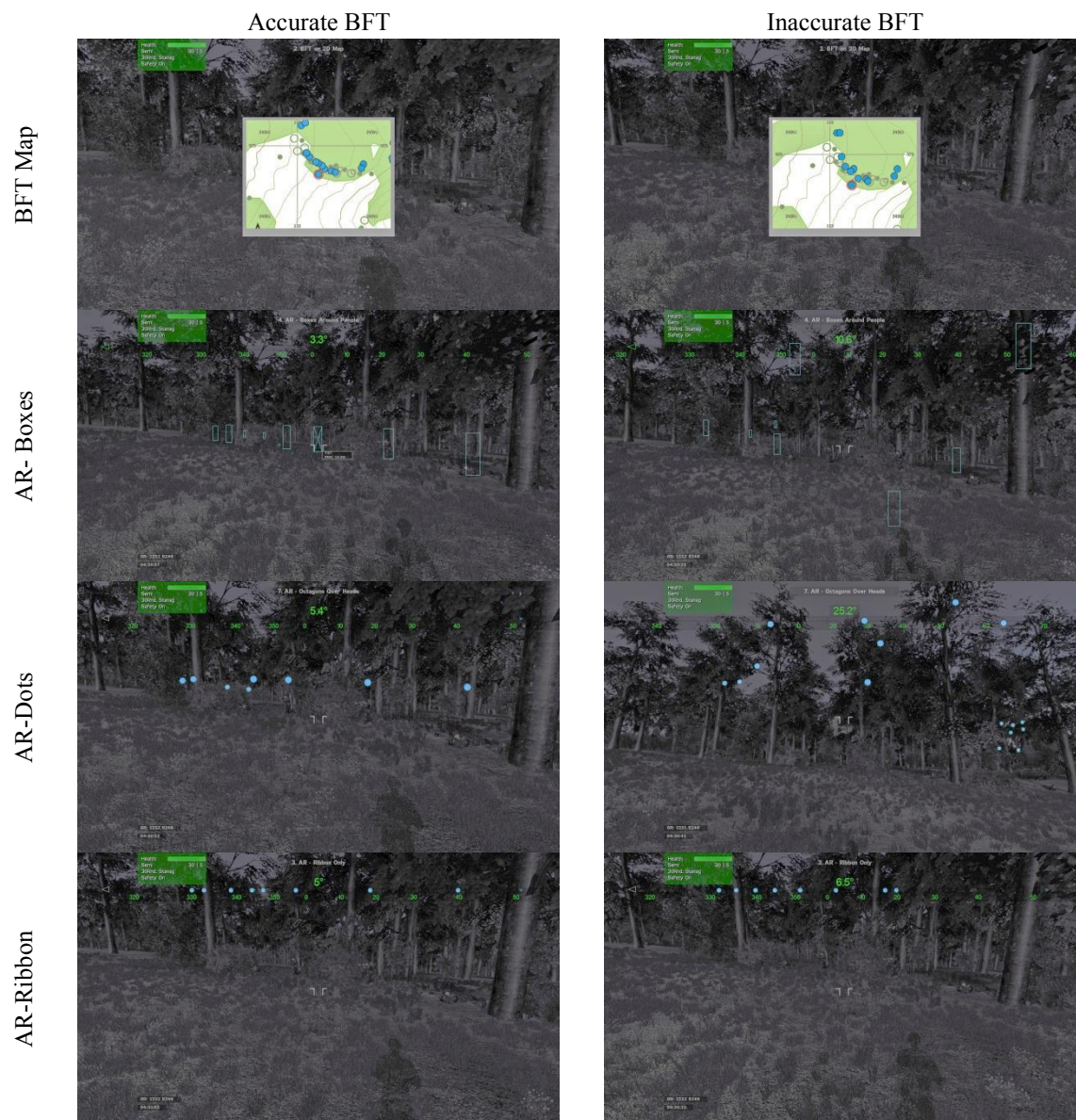
In this condition, the BFT information was continually presented in a simulated head-up display. A blue box is presented around each friendly soldier's torso. The size of the box is proportional to the range of the friendly soldier. A bearing ribbon is presented near the top of the screen with information regarding the participant's heading and a waypoint marker is visible representing the intended assault position. When the BFT was accurate, the boxes are clearly aligned over each soldier's torso (see Figure 3, second row, left column). However, when the BFT was inaccurate, the blue boxes are randomly placed in the vicinity of the actual soldier's location (see Figure 3, second row, right column). In this condition, both the horizontal and vertical error and the distance to other soldiers will affect the appearance of this visualization.

#### **3.1.4.4 AR-Dots**

This condition is similar to the AR-Box condition except that instead of boxes, blue dots were presented over each blue force soldier's head. When the BFT was accurate, the blue dots hovered over the participant's head indicating the friendly soldier's current position in the participant's forward view (see Figure 3, third row, left column). The size of the blue dot becomes smaller as the range of the respective friendly soldier increases. This condition also has a bearing ribbon, as in the AR-Boxes condition. A waypoint marker is also presented indicating the location and distance of the assault position. When the BFT was accurate, the blue dots are clearly aligned over each soldier's head. However, when the BFT was inaccurate, the blue dots are more haphazardly in the vicinity of the actual soldier's location (see Figure 3, third row, right column). Horizontal error and vertical error both affects the presentation of the BFT information.

#### **3.1.4.5 AR-Ribbon**

In the AR-Ribbon condition, blue dots representing friendly soldier locations are continually represented in the bearing ribbon with blue dots. The advantage of this display is that display method is that it reduces clutter and is not affected by vertical error and distance. However, it is less intuitive and the participant is required to estimate friendly soldier positions based on the blue dots in the ribbon. In the AR-Ribbon, the effect of signal inaccuracy is negligible. While the blue dots do not perfectly align with the soldier's bearing, there is no vertical error (Figure 3, bottom row).



*Figure 3: Examples of the eight BFT conditions.*

### 3.1.5 Scenarios and Task

All of the missions in Experiment 2 involved conducting a hasty attack on an enemy position. The missions were developed with constant consulting from QTAC Inc. using former CAF infantry soldiers as Subject Matter Experts (SMEs). The missions all take place in the early morning (approximately 4:20 a.m.–4:40 a.m.). Each mission occurs in a relatively heavily forested area where the coverage from the foliage and the time of day makes it difficult and sometimes impossible to visually ascertain the position of other friendly soldier positions.

The participant played the role of a platoon 2IC infantry soldier in charge of the firebase team while the PC (who is a simulated agent) leads the two assault groups. Each mission begins with the platoon receiving their orders to conduct a hasty attack on the enemy position. The participants are given the attack plan and the time when it will occur (H-Hour)<sup>3</sup>. After receiving their orders, the assault groups begin moving to the assault position which was either to the right or left of the enemy position. The assault teams required several minutes to move to the assault position. If the attack goes as planned, the participant is required to order firing on the enemy position at one minute prior to H-Hour. At H-Hour, the assault team will begin their assault of the enemy. The participant must order the firebase to shift their fire to the left or right (to provide cover for the assault teams) and avoid firing upon their own forces. A successful mission ends when the assault groups finish their attack on the enemy and have maintained control of the enemy site.

Nine experimental missions were created. In eight of the nine missions, an unexpected event occurs that can potentially compromise the success of the mission. The event in each of the nine missions is listed in Table 3.

**Table 3:** *A list of the critical events in each mission presented in Experiment 2.*

<ul style="list-style-type: none"> <li>(a) The assault team arrives in the wrong assault position.</li> <li>(b) The assault team becomes lost and never arrives at the assault position.</li> <li>(c) An unknown blue force is visible in the vicinity but is far enough that they would not compromise the assault plan.</li> <li>(d) The assault team is delayed arriving at the assault position.</li> <li>(e) The assault team encounters enemy forces while on route to the assault position.</li> <li>(f) The enemy begins to patrol the area close to the assault position.</li> <li>(g) Additional enemy forces appear at the enemy position.</li> <li>(h) The enemy leaves their post while the assault team is still moving into position.</li> <li>(i) An unidentified friendly force, unaware of what is happening, appears in the line of fire.</li> </ul>
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The participant's task during the mission was to maintain situation awareness of the enemy, the assault team, the time relative to H-Hour, and the surrounding environment. No radio communication between the firebase and assault team was available. At predetermined points in each mission, the participant was required to provide a situation report which consisted of answering questions (with a drop-down menu) regarding the status of enemy forces, friendly forces, and the participant's current decision to continue with the attack or to withdraw the attack. If the participant noticed anything unusual (i.e., the critical events in each mission), they were instructed to provide a manual report of the situation as soon as they noticed the event. At any point, if the participant believed that the mission had been jeopardized and they needed to withdraw the attack, he or she had to manually report to the PC their recommendation to withdraw, which would result in the end of the scenario.

If the participant believed that the mission was going to plan (or can be successful despite unforeseen events), he or she had to initiate the firebase attack at one minute prior to H-Hour (or when he or she deems it appropriate to attack). Once the assault team began their assault, the participant must also give

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<sup>3</sup> H-Hour is a military term for the hour (or time) when a major military event is planned to take place.

The orders to shift the firebase attack. The mission ended when the mission was successful, when the enemy kills the assault team, if the participant chose to withdraw the attack, or after 10 minutes wherein the mission will timeout.

### **3.1.6 Procedure**

Participants were first provided informed consent and a short briefing of the study. Afterwards, the participant was seated at a workstation. Each workstation had a desktop computer running VBS2, a headset, a pad of paper, and a pen. They then received approximately 30 minutes of practice consisting of training on VBS2, general task familiarity, and familiarity with the different forms of BFT. The practice involved running participants through two practice missions. In the first practice mission, no BFT was used and the mission went as planned. This mission was initially demonstrated by the experimenter on a large monitor in the room. During the demonstration, the experimenter stressed all of the important elements of the task. For example, participants were encouraged to jot down H-Hour, grid references and the plan for the attack. As well, the participant was continually encouraged to have SA on the situation and make the proper decision to withdraw the mission or attack the enemy. After the demonstration, the participants played the first practice mission and they were allowed to ask questions as necessary. In the second practice mission, the experimenter first demonstrated the different forms of BFT and showed participants how to toggle through the various BFT options as necessary. The players then played the mission which had an unexpected event. In this mission, while the assault team was moving to the assault position, an enemy vehicle drove towards the firebase and notifies the rest of the enemy forces.

After the participants were familiar with the task, they performed the nine experimental missions. The experimental conditions were counterbalanced such that all participants experienced each of the nine conditions once. After the end of each mission, participants were required to perform a situation awareness task related to the mission. The participant was given a map of their location and they had to geographically locate the final positions of all enemy and friendly units on a map. Participants then had to complete the NASA-TLX as a measure of their workload during the mission. After all conditions were completed, participants were debriefed on the study. The entire study was approximately three hours in duration.

## **3.2 Results**

Several dependent variables were measured in Experiment 2 (Table 4) and they were grouped into four categories decision-making, event detection, instances of friendly fire and geositional awareness.

**Table 4:** *A list of the dependent variables used in Experiment 2.*

<u>Attack Decision</u>	
Attack Decision Accuracy	Decision in each mission to attack, withdraw, or wait.
Attack Decision Time	Time in seconds to reach the Attack decision.
<u>Event Awareness</u>	
Event Awareness Accuracy	Accuracy of reporting anomalous events.
Event Awareness Time	Time to report anomalous events (in seconds from the beginning of the scenario).
<u>Friendly Fire</u>	
Frequency of wounding or killing blue force soldiers.	
<u>Geo-positional Awareness</u>	
Euclidean Distance	The distance between the ground truth position of blue force assault units and the participant's estimated mapped position of blue force assault units.

### **3.2.1 Attack Decision**

#### **3.2.1.1 Attack Decision Accuracy**

For each mission, participants had to decide whether to conduct the attack, withdraw the attack, or wait. The correct response for each mission was originally determined by consulting with SMEs who helped develop the missions. The participants' accuracy was scored by taking their initial decision to attack or withdraw and compared against the predetermined attack/withdraw decision of each mission. After our initial examination of the data though, it was evident that some missions were more ambiguous, resulting in a similar number of participants choosing to attack or withdraw. As a result, we consulted three additional CAF commanders with experience leading teams in attacks to review the ambiguous missions. The SMEs were provided with an omniscient view of each mission and were asked how they would respond in the given situation. Their opinions were then combined with our previous judgments to arrive at the "best" decision for these missions.<sup>4</sup> In the end, we arrived at five missions where the best answer was to attack, one mission where the best answer was to withdraw, one mission where the best answer was to wait, and two missions where the best answer was to either wait or withdraw.

The accuracy for each participant in each condition was scored as correct or incorrect. The accuracy data comparing the five BFT conditions (including the No BFT condition) were then analyzed using a Friedman's rank test for correlated samples at each level of signal accuracy. The mean ranks for each

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<sup>4</sup> Subsequent to the SME evaluations, we agreed that there could be more than one possible correct answer in two of the scenarios. In one case, we rejected the SMEs decision entirely because their decision would have led to friendly fire in our simulation. The SMEs were considering the scenario from a real-life perspective and expected the assault teams to react accordingly. However, in simulation, our assault teams would not have reacted as they had planned and would have proceeded to walk into the line of fire.

condition are presented in Table 5. Contrary to our hypothesis, for both the accurate BFT conditions and the inaccurate BFT conditions, no significant differences were found ( $\chi^2(4, N = 35) = 2.75, p = .60$  and  $\chi^2(4, N = 34) = 1.10, p = .90$  respectively).

**Table 5:** Attack decision accuracy (%) and rank for each condition.

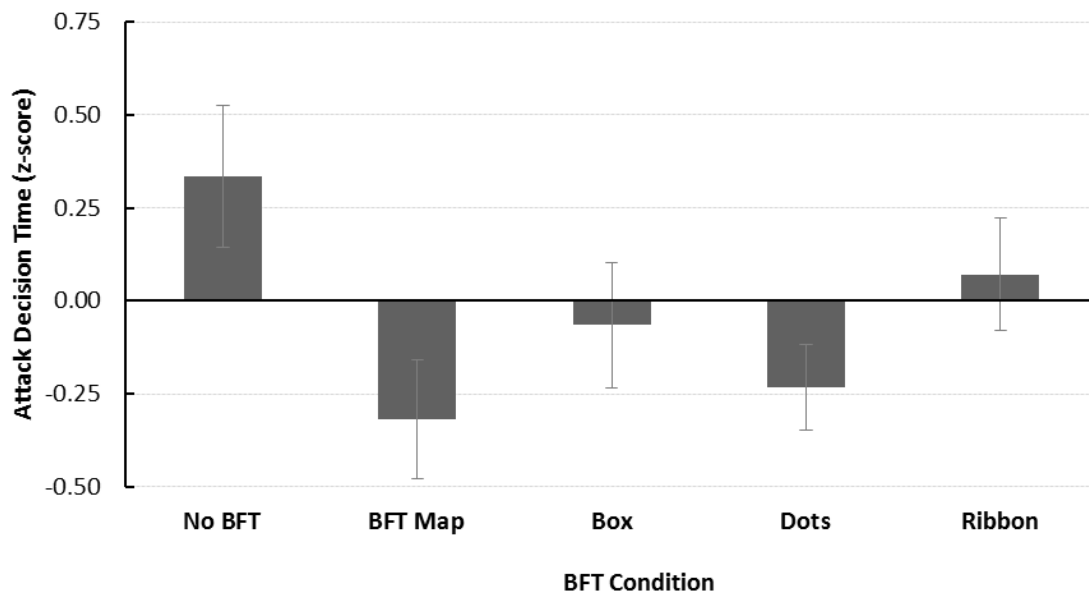
Condition	Accurate BFT (N = 35, df = 4)		Inaccurate BFT (N = 34, df = 4)	
	%	Rank	%	Rank
No BFT	34.29	2.91	35.29	2.88
BFT Map	31.43	2.84	44.11	3.10
Dots	40.00	3.06	44.11	3.10
Box	34.29	2.91	41.18	3.03
Ribbon	48.57	3.27	35.29	2.88

### 3.2.1.2 Attack Decision Time

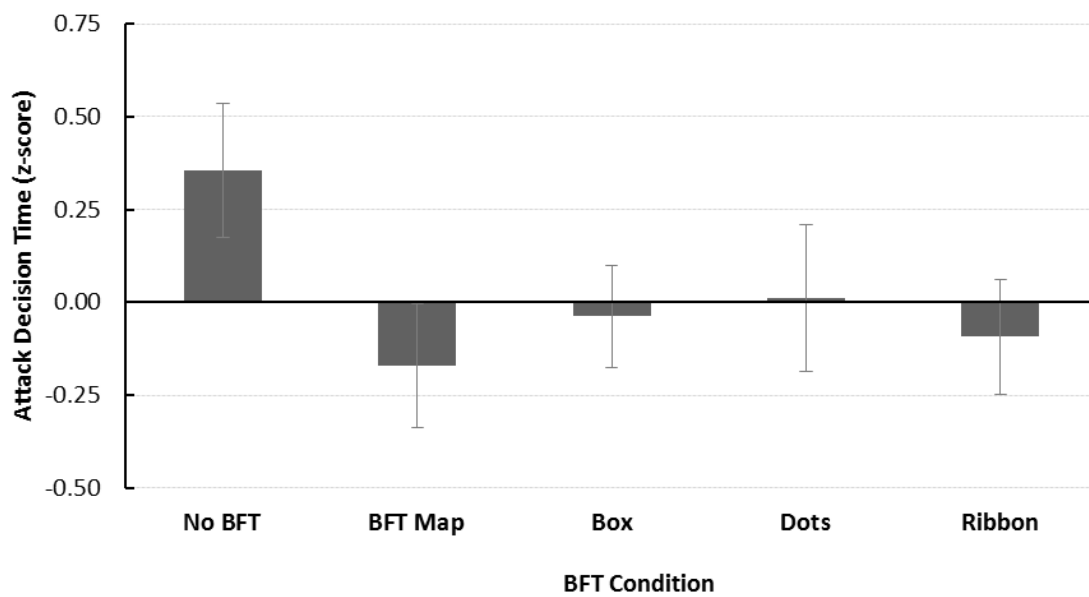
The time in seconds for participants to reach a decision was analyzed in each scenario. The action to attack or withdraw the attack was timestamped and the duration from the beginning of the trial was calculated for each mission. Because events in each mission differed with respect to when participants were able to make this decision, we normalized the attack decision time for each mission so we could compare across missions. Missions where the participant timed out were first removed and any values greater than three Standard Deviations (SDs) were omitted. This resulted in 5.6% of the data removed from the analyses.

The attack decision time was analyzed with two one-way within-subjects ANOVAs at each level of signal accuracy comparing the four BFT conditions and the No BFT condition. When the signal accuracy was perfect, there was a significant main effect,  $F(4, 124) = 2.55, p = .05$ , but when the signal accuracy was not perfect, the effect was not significant,  $F(4, 128) = 1.76, p = .154$  (Figures 4 and 5 respectively). The significant effect for the accurate conditions was followed up with paired comparisons of each BFT condition against the No BFT condition, using a Bonferroni correction to control for Type I errors. The BFT Map condition resulted in significantly faster attack decision times than the No BFT condition ( $p = .009$ ). There was a marginal difference between the AR-Dots condition and the No BFT condition, ( $p = .028$ ). The AR-Box and AR-Ribbon conditions were not significantly different from the No BFT condition ( $ps > .05$ ).

In addition, to analyze whether BFT signal accuracy had any effect on attack decision time, pairwise comparisons for each BFT type comparing the levels of signal accuracy were performed. In each case, signal accuracy had no effect on the decision time to attack or withdraw their attack ( $ps > .25$ ).



**Figure 4:** Attack decision time (shown as z-score) for each BFT condition, when signal accuracy was perfect.



**Figure 5:** Attack decision time (shown as z-score) for each BFT condition, when signal accuracy was imperfect.

### 3.2.2 Event Awareness

#### 3.2.2.1 Event Awareness Accuracy

Each mission had one unexpected event that had the potential to jeopardize the mission. Participants were instructed to perform a manual report if they noticed anything that could affect the mission. Alternatively, at predetermined points in the mission, we also asked participants to provide situation reports. These reports were used to determine whether participants noticed the events in each mission. The answers in the reports were scored and the accuracy for detecting the event was calculated.

A five-level Friedman's rank test was performed, first on the four accurate BFT conditions, plus the No BFT condition and then another Friedman's rank test using the four Inaccurate BFT conditions, plus the No BFT condition. The mean ranks of the accurate BFT conditions, the inaccurate BFT conditions and the No BFT condition is provided in Table 6.

For the accurate BFT conditions, the Friedman's rank test was significant,  $\chi^2(4, N = 35) = 23.56$ ,  $p < .001$ . We then conducted the four-level Friedman's test on only the BFT conditions. This test was not statistically significant,  $\chi^2(3, N = 36) = 3.51$ ,  $p = .32$ , suggesting no difference in event detection amongst the accurate BFT conditions. However, pairwise comparisons (applying a Bonferroni correction for Type I errors) between the four BFT conditions and the No BFT condition using the Wilcoxon signed rank test, found that participants accurately detected the event more often when using the BFT Map, the AR-Box and the AR-Dots conditions ( $ps \leq .001$ ). The effect of the AR-Ribbon condition compared to the No BFT condition was marginally significant, ( $p = .025$ ).

**Table 6:** Event awareness accuracy (%) and rank for each condition.

Condition	Accurate BFT (4, N = 35)		Inaccurate BFT (4, N = 35)	
	%	Rank	%	Rank
No BFT	34.29	2.21	35.29	2.26
BFT Map	74.29	3.21	73.53	3.22
Dots	77.14	3.29	70.59	3.15
Box	80.00	3.36	73.53	3.22
Ribbon	62.86	2.93	70.59	3.15

Note that the No BFT condition was used in both the Accurate and Inaccurate BFT analyses. The % and rank numbers are different because the numbers are generated relative to the other conditions in the corresponding analyses.

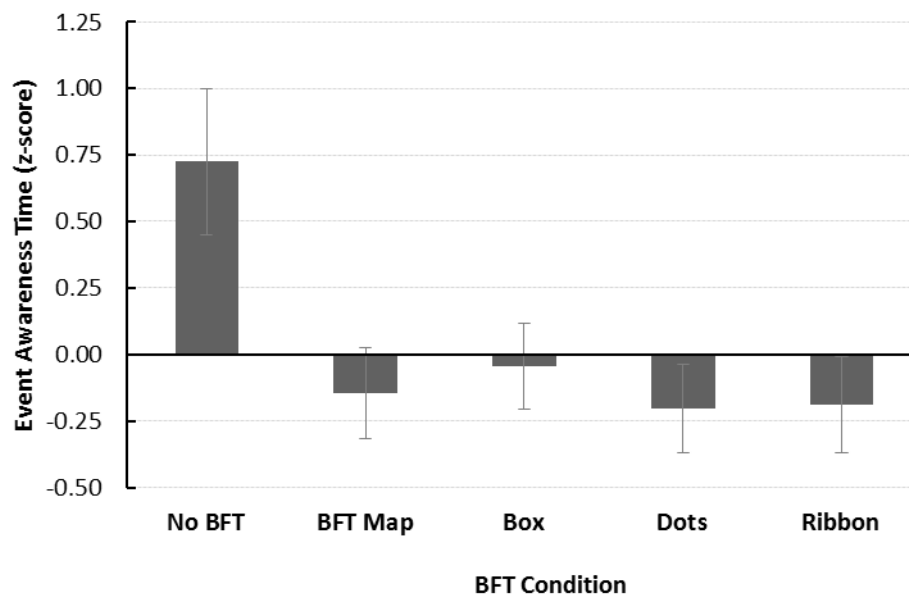
A very similar result was found of the Inaccurate BFT conditions. The five level Friedman's rank test comparing the Inaccurate BFT conditions plus the No BFT condition was also significant,  $\chi^2(4, N = 34) = 18.81$ ,  $p < .001$ . When the No BFT condition removed, the Friedman's test was not significant,  $\chi^2(3, N = 35) = .465$ ,  $p = .93$ . Again, pairwise comparisons of each of the Inaccurate BFT conditions against the No BFT condition were performed using the Wilcoxon signed rank test. In each

case, the event awareness was greater for each of the Inaccurate BFT conditions over the No BFT condition ( $p_s < .003$ ). Thus, consistent with our hypothesis, employing BFT resulted in more accurate event detection, but this was evident for the Accurate and Inaccurate BFT conditions.

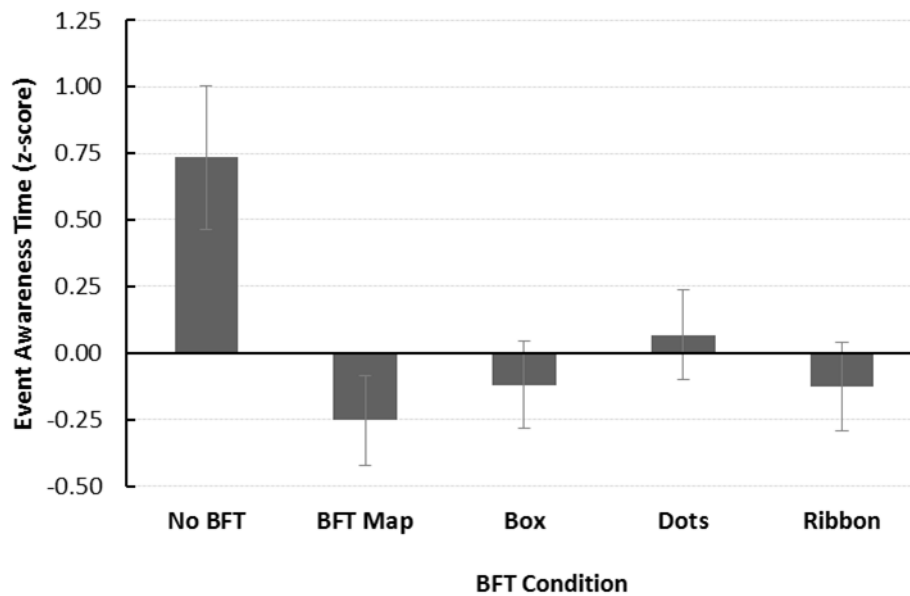
### 3.2.2.2 Event Awareness Time

When participants correctly identified an event, we recorded the time that the event was reported relative to the start of the scenario. These event detection times were then normalized and submitted to two separate five level (BFT) one-way Linear Mixed Model (LMM) analysis at each level of accuracy. As shown in Figure 6, when the BFT was accurate, it appears that the BFT conditions resulted in faster detection times than the No BFT condition; however there was only a marginal main effect of BFT,  $F(4, 93.71) = 2.38, p = .057$ . Despite the marginal effect, we conducted pairwise comparisons of each BFT condition against the No BFT condition using a Bonferroni correction to control for Type 1 errors. Only the AR-Dots condition was marginally significantly faster than the No BFT condition ( $p = .05$ ).

We then conducted the five level one-way analysis of the four BFT conditions plus the No BFT condition for the Inaccurate BFT conditions. The main effect of BFT was significant,  $F(1, 93.74) = 2.71, p = .035$ . This effect is shown in Figure 7. Pairwise comparisons (again applying a Bonferroni correction) at each level of BFT against the No BFT condition were conducted. The BFT Map ( $p = .024$ ), AR-Box ( $p = .079$ ) and AR-Ribbon ( $p = .077$ ) conditions were all marginally faster than the No BFT condition. The AR-Dots condition was not statistically different from the No BFT condition.



**Figure 6:** Event awareness time (shown as a z-score) for each BFT condition, when signal accuracy was perfect.



**Figure 7:** Event awareness time (shown as a z-score) for each BFT condition, when signal accuracy was imperfect.

Similar to the Attack Decision Time, pairwise comparisons were also conducted for Event Awareness Time for each BFT type at each level of signal accuracy. Again, no effect of BFT signal accuracy was found for Event Awareness Time ( $p > .11$ ).

### 3.2.3 Friendly Fire

Only 3.4% of the missions resulted in a case of friendly fire. The cases were also distributed across the BFT types (see Table 7) and as a result, no further statistical analyses were performed.

**Table 7:** Percentage of friendly-fire instances across BFT conditions.

	No BFT	BFT Map	Box	Dots	Ribbon
Accurate		2.8%	2.8%	0%	0%
Inaccurate	2.9%	2.9%	2.8%	0%	2.8%

### 3.2.4 Geo-positional Awareness

#### 3.2.4.1 Euclidean Distance of Assault Teams

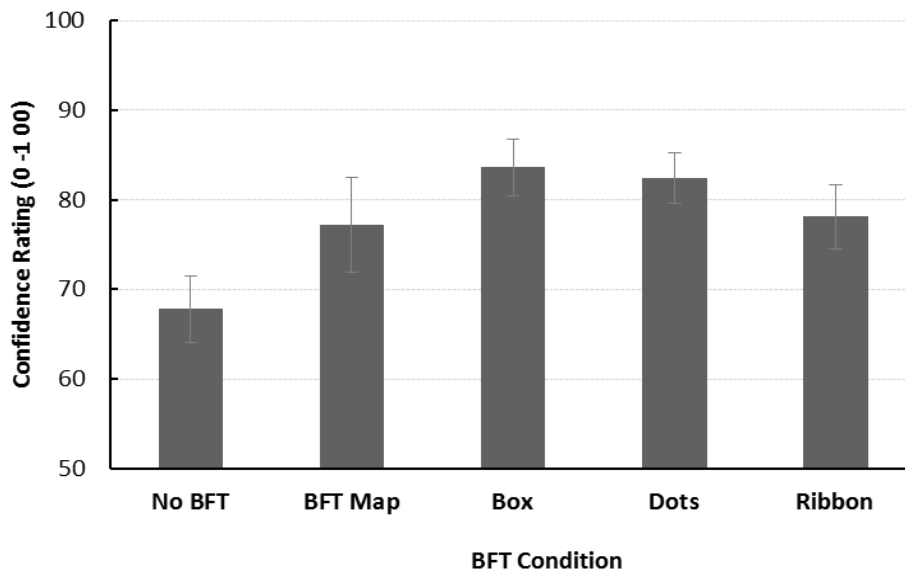
After completing the mission, participants were asked to mark the location of each entity on a map. In particular we were interested in the location of each of the assault teams since it is these two teams that are presented on the BFT displays. The Euclidean distance of each assault team relative to the ground truth of these locations was calculated. Each assault team's distance was calculated separately rather than

aggregated because in some scenarios the assault team became separated during the attack. The Euclidean distance of each assault team were then submitted to two separate one-way five (BFT conditions) Linear Mixed Model (LMM) analyses, one for signal accurate BFT and one for signal inaccurate BFT.

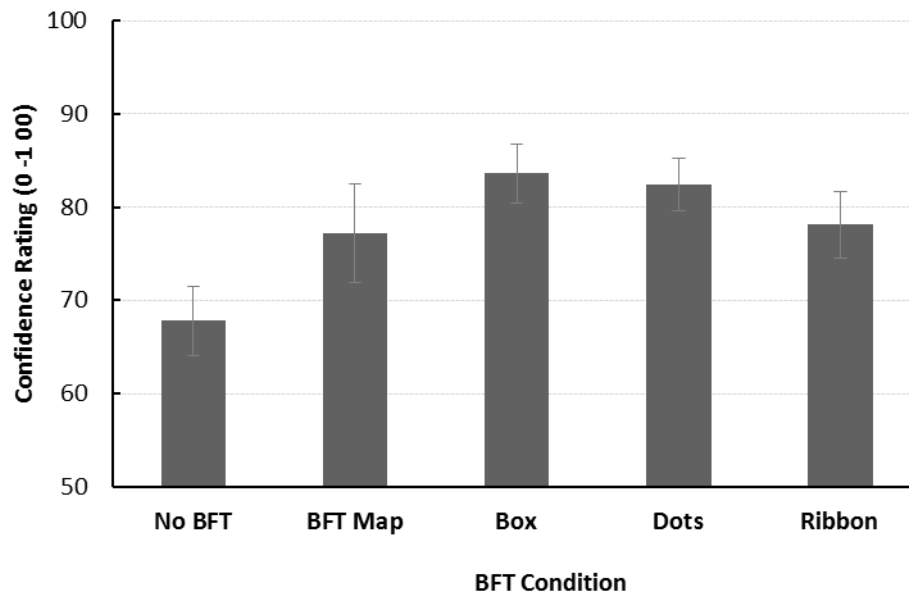
For the first assault team, there was no main effect of BFT when the BFT signal was accurate,  $F(4, 174) = .77$ ,  $p = .546$ , nor when the BFT signal was inaccurate,  $F(4, 177) = .905$ ,  $p = .462$ . Pairwise comparisons were then performed to examine the effect of accuracy at each level of BFT. No significant effects were observed ( $ps > .12$ ). Similar null effects were found for Assault Team 2. There was no main effect of BFT when the signal was accurate,  $F(4, 175) = .576$ ,  $p = .68$  and no significant effect of BFT when the signal was inaccurate,  $F(4, 175) = .569$ ,  $p = .67$ . Pairwise comparisons at each level of accuracy for each BFT also produced no significant results ( $ps > .09$ ). Hence, for both assault teams, in opposition to our hypothesis, the type of BFT used did not affect how well participants could re-create the map of their operational area.

### 3.2.4.2 Confidence Ratings for Mapping Entities

Subsequent to mapping the individual entities on the 2D map, participants rated their own confidence on a scale of 0–100, that the map they produced was accurate. Again, we first submitted the confidence rating data to two separate one-way five (BFT conditions) Linear Mixed Model (LMM) analyses at each level of BFT signal accuracy. Mean confidence scores for both the Accurate and Inaccurate BFT conditions are presented in Figures 8 and 9. When the signal accuracy was accurate, there was a significant effect of BFT,  $F(4, 132) = 3.94$ ,  $p = .005$ . Pairwise comparisons with a Bonferroni correction, suggests that participants in both the AR-Box ( $p = .005$ ) and AR-Dots ( $p = .01$ ) conditions were significantly more confident than when in the No BFT condition. However, the BFT Map and the AR-Ribbon condition were not significantly different from the No BFT condition. When the signal accuracy was not perfect, there was a marginal effect for BFT,  $F(1, 132) = 2.26$ ,  $p = .066$ . None of the pairwise comparisons were significant ( $p > .132$ ).



**Figure 8:** Confidence ratings for mapping entities for each BFT condition when signal accuracy is perfectly accurate.



**Figure 9:** Confidence ratings for mapping entities for each BFT condition when signal accuracy is inaccurate.

### 3.3 Discussion

The results of Experiment 2 provide a mixed picture regarding the overall benefit of BFT on dismounted soldier performance. First, there is an advantage for using BFT over not using BFT, but the advantage is limited. When using BFT, participants had greater awareness of events; participants reported events in our scenarios faster and more accurately than in the No BFT condition. This increased situation awareness led to faster attack decision times in the BFT Map and AR-Dots conditions (when the BFT was perfectly accurate). However, even though participants noticed events more quickly, there was no difference in the accuracy of decisions when using BFT versus having no BFT. Second, in the AR-Box and AR-Dots conditions, when BFT was accurate, participants exhibited greater confidence when replotting blue force positions on a map. When BFT was inaccurate, this effect was only marginal. Third, as with Experiment 1, there was little effect of BFT signal accuracy on mission performance suggesting that with a BFT system with up to 10 metres error, soldiers can still benefit from the positional information. Finally, while AR versions of BFT showed superior performance to having no BFT, there was no benefit for using AR versions over a digital map with BFT. This suggests that presenting BFT information in AR does not appear to provide any additional benefit (or cost) relative to a map-based BFT system.

Superior event detection was evident when using BFT. All of the BFT conditions significantly outperformed the No BFT condition, with the exception of one (which was marginally significant). While the latency variable (Event Awareness Time) the data were less clear cut (with several marginal effects), but they all exhibited the same trend with BFT conditions generally faster than the No BFT condition (Figures 6 and 7). The several marginal effects for this variable are potentially attributable to the low power of the analysis. Recall that many participants did not notice the events at all (Table 6), so these

instances were excluded from the latency analysis. Only those instances in the No BFT condition where participants noticed the events were included, and as a result, fewer data points were included in the analysis.

Despite having noticed the events and responding to them more quickly, the BFT conditions did not necessarily result in faster decision times or more accurate decisions. Faster attack or withdrawal decisions were only faster in two of the accurate BFT conditions (BFT Map and AR-Dots). While ideally faster and accurate situation awareness of events would have resulted in faster and more accurate decisions, SA and decisions are not always tightly coupled [44]. In this study, it may be that even though participants (with BFT) noticed events faster, they still waited to see how the scenario would unfold (or until H-Hour had passed) before making a final decision. For example, if the assault teams came in contact with enemy troops while en route to the attack position, the participant may wait to see if the assault teams could overcome the enemy and then still continue with the hasty attack plan. This likely resulted in enough variability that we did not see any meaningful changes to decision-making. Moreover, as we alluded to in Section 3.2.1.1, our scenarios were quite realistic and complex, and did not always have clear solutions. This level of uncertainty likely also resulted in increased noise in the attack decision accuracy data. Therefore, despite the fact that BFT employment does not necessarily result in faster and accurate decisions, we argue that using BFT does improve a soldier's situation awareness and this allows for a *greater potential* for faster and better mission-related decisions [44].

Subjectively, the employment of BFT resulted in improved soldier confidence in their own awareness of blue force positions. When using an accurate BFT, participants were more confident in their knowledge of where people were, in particular when using the AR-Box and AR-Dots. In these conditions, the blue force display is presented in the participant's forward view and the blue force visualizations were perfectly aligned with the movements of blue force positions. The increased confidence, however, did not translate to the actual accuracy of our participants' ability to reconstruct the map of the battlefield after the mission.

It may be that, overall participants were more confident of their SA of blue force positions, but the accuracy of any individual BFT position was not particularly important. Instead, the participant was able to use the group of BFT signals which provided a sufficient estimate of each assault team's position and this rough estimate was sufficient for the task. Interestingly, participants did not seem to be overly aware of the inaccuracy of the BFT in the inaccurate conditions. Not a single participant in our study commented on the inaccuracy or even indicated to us that the BFT looked strange, even though in the AR-Box and AR-Dots conditions, the visualization looked haphazard and nonsensical at times (e.g., blue dots or boxes floating in trees due to vertical errors).

The lack of any clear benefit of AR displays over the BFT Map is somewhat surprising. When our simulated AR displays are initially shown to participants, they are often met with enthusiasm as the location of soldiers becomes abundantly clear. However, there are at least a couple of reasons why AR-based BFT failed to show any significant advantage over a map-based BFT. First, soldiers work with 2D maps routinely and thus the cognitive translation of blue forces from a map to the physical location in one's field of view may not be overly demanding for soldiers. So, while AR-based BFT are intuitive, in practice, they may not provide a great deal of cognitive benefit. Second, both map-based and AR-based BFT systems have certain advantages and disadvantages. While maps require some level of cognitive spatial translation, maps also provide a better global view of the battlefield. As evidenced in Experiment 1, soldiers can pan and zoom their maps to see other aspects of the battlefield not directly in their line sight. Furthermore, in our renditions of AR, while it was easy to determine the bearing of other blue

forces, it was difficult to estimate ranges. With the map, it was easier to interpret the range of other blue forces. Thus, while AR-based BFT might be more intuitive, the information provided via a map may have been more useful for mission performance. Thus the benefit of the AR was negated by the difficulty to gauge range and the difficulty of seeing blue forces not in the participant's field of view.

Despite the null findings for BFT signal accuracy and the use of AR, the results of Experiment 2 are informative. Experiment 2 showed a clear statistical benefit for using BFT as participants were more accurately and more quickly able to detect and report events occurring during their mission with BFT. The lack of any signal accuracy effects or AR effects (over a map-based system) provides insight into how soldiers use BFT information and provides guidance for the CAF on whether to invest in more accurate BFT or AR-based systems, such as the US Army's ARC4 and JBC-P systems which promises faster more accurate BFT [5] [20].

### **3.3.1 Limitations**

As with any simulation based study, one of the primary limitations of this work is weaker ecological validity. While our participants commented on the realism of the missions (e.g., shooting in the dark at a nearly invisible targets, execution of the hasty attack), they also commented on some weaknesses. For example, many participants complained that in reality, they would also have radio communication to support their SA of other blue forces (although others also said that radio communication is often not possible or not working properly). We could not simulate radio communication in this study and enabling radio communication would have confounded any BFT effects. Also, some participants commented that

the constrained ability to make decisions was artificial. For example, participants occasionally initiated an attack, but then wanted to withdraw soon afterwards, but they were prevented from doing so. These behaviours were the result of simulation issues with VBS2 and unfortunately were unavoidable.

We also could not realistically simulate all of the characteristics of BFT devices. For example, the limitations of VBS2 constrained us to present our 2D maps with north on top, like a paper map. Obviously, we also could not simulate the authentic interactions of using a hand-held BFT device and AR devices that might have weight, resolution, and interface interaction issues. Our simulations were also limited in their features in order to isolate the BFT effect; a realistic BFT system might have other advantages and functions that we did not consider in this study. Moreover, our simulation does not capture the actual complexities of tracking errors which can be the result of the signal strength, multipath, environmental conditions, fusion algorithms, and sensor behaviour. Therefore even though we did not find a strong effect of BFT signal accuracy, the effect might exist in a field mission.

While the simulation is not realistic in some ways, we also traded experimental rigour in our study design for more realism in Experiment 2. First, as mentioned in Section 2.1.4, the tasks to achieve the goals of the mission in the No BFT condition and the BFT conditions are quite different (which is realistic) but difficult to compare statistically. Second, the No BFT condition was clearly at a disadvantage (relative to other conditions) since the attack was at night and it was difficult (although not impossible) to visually maintain SA on one's assault teams. However, nighttime attacks are common as they provide the CAF with an advantage over many of our adversaries, so we decided to use nighttime attacks in our scenario. Third, the decision to attack or withdraw the attack was not always clear. Even our SMEs who had the advantage of having all of the information in each scenario could not always agree on the correct course of action. This suggested to us that the conditions of the scenarios met the complexity of a real situation. However, from an experimental context, it was difficult to evaluate

accuracy of decisions and this may have obscured some of the effects of the BFT. Last, we chose only to use CAF army personnel who were (primarily) infantry or combat engineers with a rank of MCpl or Sgt to be participants because of their training and experience to lead such attacks like the hasty attack. As a result, we had difficulty reaching our sample size and had to also include some junior officers with sufficient leadership experience. Arguably, the current sample may not have provided us enough power to detect all of the effects as a result. In particular, we limited the data in the Event Awareness Time (EAT) and this might have resulted in too few data points to see significant effects. Still, many effects were clear and there were trends to suggest benefit of using BFT over not using BFT.

The current study also only focused on hasty attacks from the perspective of a relatively stationary soldier. There are other tactics wherein the soldier is on the move which might benefit from BFT or AR that are worth exploring. We also did not take into account those situations when today's BFT devices will not provide good information such as when soldiers are performing a room clearing and the blue forces are indoors. However, we assume that in these situations, soldiers would simply turn off or not rely on their BFT.

### **3.3.2 Lessons Learned**

The development of realistic simulated missions will be an ongoing challenge for future work using VBS2. In Experiment 1, the missions were overly simplistic and very constrained. In Experiment 2, our team spent a number of months to produce a new set of missions based on a navigation task. But these missions were then deemed inadequate when presented to former CAF personnel who argued that BFT is

not a navigation tool, so the task was inadequate. In order, to develop realistic missions, we then worked with former CAF members and spent a great deal of time planning, redeveloping, and testing the missions until they were deemed satisfactory.

Even after we developed the nine hasty attack missions with ongoing SME support, we found that after running the experiment, the missions were not always comparable with respect to participant performance. This made it difficult to simply average across our experimental conditions due to the variability across missions. As such we had to change our time-based metrics to z-scores to be analyzed statistically. However, this approach is less understandable to those who do not have a statistical background and requires some explanation.

We also tried to create missions that had a clear correct or incorrect response to attack or withdraw the attack. Unfortunately, as we alluded to in Section 3.2.1.1, there was quite a bit of variability on how to respond and even SMEs could not always agree on a clear response.

Thus, future studies should allow for time to develop realistic missions with CAF SME involvement. The failure to include CAF SMEs in the development process will likely result in participants rejecting the study and not accepting the results of the research. Missions need to be well thought through and conceived. They must be sufficiently realistic, but also constrained enough that participants do not have an infinite number of ways to deviate from the intended goal of the study. They also need to meet the constraints of any simulation software. Moreover, experimenters are encouraged to think through the analysis when employing simulated missions. Unlike controlled studies where trials are repeatable and comparable, creating realistic missions will likely result in challenges from a statistical analysis point of view.

Another challenge we encountered in this project was the availability of qualified personnel to run as participants. The current study required soldiers with sufficient experience leading dismounted troops and thus we originally limited our participants to the infantry soldiers or combat engineers with a rank of Sergeant or Master Corporal. However, our ability to recruit a sufficient sample size with participants with these specific qualifications proved challenging. In the end, we also accepted some officers with sufficient combat or leadership experience in order to increase our sample size. We expect that participant recruitment will continue to be a challenge and therefore future studies need to either allow the time to collect the necessary data or be willing to reduce their sample size and plan their analyses accordingly.

Last, an ideal simulation-based study looking at the effect of dismounted soldier BFT would involve multiple soldiers playing in the same simulated environment as a team. However, team-based simulations necessarily require participants to communicate and some individual autonomy to make decisions. From a simulation point of view, this type of study would be very difficult to develop, since it would require anticipating individual decisions and communication and then developing potential responses to those actions in the simulated environment (e.g., programming how enemy forces might react to various individual decisions). The experimenter would likely lose experimental control over the mission and it is unlikely that the missions would be comparable across different teams. Also, the recruitment of such teams would be difficult to accomplish. Therefore we caution increasing the complexity of simulated laboratory experiments for dismounted troops. While a team-based study is theoretically ideal, it may be too difficult to develop well with limited resources and may be difficult to execute with a small population of participants.

### **3.3.3 Future Research**

Future research on BFT should further explore its potential for supporting CAF operations. As mentioned above, we limited our study to dismounted soldiers conducting a hasty attack, but other tactics might also see benefit from BFT that we have not considered. These studies could be run in simulation but should also be verified in field studies using actual BFT systems, taking into account not only performance metrics but also soldier input regarding its potential benefits and costs.

Other common human factors concerns should also be addressed regarding the use of BFT. Future research could examine whether BFT (and C2 information in general) has the potential to cognitively and visually overload dismounted soldiers. Unlike the command teams at the brigade or company level, soldiers at the platoon level and below, have extreme physical challenges that result in unique levels of cognitive overload; thus they may be more susceptible to be overwhelmed with too much information. Moreover, future studies should also examine whether the provision of BFT will lead to trust and over-reliance issues and how this will impact soldiers when the technology fails. It is unclear whether soldiers are able to recover from technology failures and return to their core skills to perform mission planning, navigation, and combat identification skills. If these skills have degraded to the point that they are unable to accomplish missions without the technology, then studies can investigate how the CAF can better train soldiers to work with and without technology.

BFT is only one capability that is associated with the digital battlefield. Other capabilities and information can also be presented along with BFT to provide ground soldiers and commanders with greater SA. For example, the symbology used in the current study only presented the location of a blue force soldier. Future studies could study the necessity of providing information such as the identification of the soldier, the unit or group that he or she belongs to, track the weapons and equipment status, and biometrics data of the soldier which can be used to understand injury or physical readiness.

In addition, as Canada moves closer to network-centric warfare and mission-relevant information is disseminated to the soldier, it raises the question of who requires what information? Information needs assessment could be conducted at all levels of command to understand how information could be properly disseminated given today's military structure. Alternatively, by providing mission information to all levels of command, the army's command structure may need to change as a result. For example, lower level of commanders may be able to make quicker and more reliable decisions without going through their chain of command, thereby more efficiently conducting operations. Thus, in the future, the command structure may be reduced or the hierarchy of command may alter as a result.

Last, more research should be directed on the potential use for AR in theatre and for training. AR is becoming more and more advanced and a potential disrupting technology. Indeed the US Army is already moving in this direction with its ARC4 system [6]. While the current study showed little benefit for BFT information displayed in AR, we only examined AR in a limited fashion. A great deal of information can be presented through AR and its potential for supporting the soldier in an intuitive fashion makes it an attractive technology for future investment. However, like any technology, the human factors associated with using such devices needs to be further explored to discover not only its advantages but also potential disadvantages or issues when used in theatre.

## 4 Conclusion

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The present paper is one of only a handful of empirical papers studying the effects of BFT on soldier performance. We report that BFT does support soldier SA and this translates to more accurate and faster responses to mission events. Thus, our data supports the anecdotal assertions that BFT helps to reduce uncertainty in theatre. While our data did not find much improvement on mission decisions, we argue that BFT improves SA and thus improves the potential for commanders to make faster and more effective decision. In addition we found that inaccuracies in BFT localization of soldier positions had little effect on participant performance, but that accurate BFT does provide more confidence in positional awareness. As well, our simulated AR-based BFT had no additional benefit to performance relative to a standard map-based BFT, although all BFT conditions outperformed conditions without BFT.

The present study suggests that the CAF is moving in the right direction with ISSP and LCSS by providing BFT to all soldiers. However, as technology advances and BFT provides greater precision for localizing entities and advanced display capabilities become available through AR, the CAF needs to move cautiously before investing more into BFT as the overall benefit to soldiers may not be worth the investment.

The current study provides some evidence for the benefits of BFT, but the data were limited to a small simulated study which was naturally constrained in terms of realism, but also in the way we were able to display the BFT information. We encourage future simulation and field research, not only on the topic of BFT, but on the general topic of the digital battlefield in network-centric environment. As our military becomes more and more connected both to information and each other, it will enable soldiers at the individual level, teams of soldiers, and the Canadian army as an organization to perform tasks much differently than how operations are achieved today. However, these capabilities could also come with some negative human factors consequences and have some unforeseen ripple effects that can be mitigated with advanced research.

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## List of Symbols/Abbreviations/Acronyms/Initialisms

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2D	Two Dimensional
2IC	Second in Command
2Lt	Second Lieutenant
ANOVA	Analysis of Variance
AR	Augmented Reality
BFT	Blue Force Tracking
C2	Command and Control
CAF	Canadian Armed Forces
CID	Combat Identification
CO	Commanding Officer
CPT	Captain (US Army)
DRDC	Defence Research and Development Canada
DSTL	Defence Science and Technology Laboratory
FBCB2-BFT	Force XXI Battle Command Brigade and Below-Blue Force Tracking
GPS	Global Positioning System
HMD	Head-Mounted Display
IFF	Interrogate Friend or Foe
ISSP	Integrated Soldier System Project
JBC-P	Joint Battle Command—Platform
JCR	Joint Capabilities Release
LCSS	Land Command Support Systems
LMM	Linear Mixed Model
LTC	Lieutenant Colonel (US Army)
M	Mean
MCpl	Master Corporal
NASA-TLX	National Aeronautics and Space Administration—Task Load Index
OGA	Other Government Agency
OP	Operation Officer
PC	Platoon Commander
PR	Personnel Recovery

RMS	Root Mean Square
SA	Situation Awareness
SD	Standard Deviation
SE	Standard Error
Sgt	Sergeant
SME	Subject Matter Expert
SOF	Special Operations Forces
UK	United Kingdom
US	United States
VBS2	Virtual Battle Space 2

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12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)  <b>Soldier System; Network-Enabled Soldier; Human/Soldier Performance</b>		

Today's Blue Force Tracking (BFT) systems use Global Positioning System (GPS) to track individual soldiers. In two experiments, we investigated the effects of BFT on soldier performance using a first-person computer simulation. In Experiment 1, 36 participants led a section to locate and support another force under enemy contact. They did the task with a Two Dimensional (2D) map with Accurate BFT, Inaccurate BFT, or No BFT. The results showed that when using BFT, soldiers were faster at engaging the enemy but other performance variables were not significant. They also used their BFT map more frequently compared to the No BFT condition. The inaccurate BFT did not negatively affect performance. In Experiment 2, participants led a firebase in similar hasty attack missions. In each mission, a unique event could affect the decision to attack. Participants used no BFT, a 2D map with BFT, or three different augmented reality displays. The BFT again could have 100% signal accuracy or some inaccuracy. The results showed that having BFT supported more accurate event detection and marginally faster event detection times. An accurate BFT also resulted in faster attack decisions in some conditions. However, this did not translate to more accurate decisions. BFT accuracy did not affect participants' ability to accurately locate and map blue force positions, but they had more confidence in their ability with accurate BFT systems. There was no additional benefit for augmented reality BFT over a BFT map system. The studies suggest that BFT supports mission performance even when it is not perfectly accurate, and augmented reality systems have limited benefit relative to a handheld system, at least for the tasks examined.

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Les systèmes actuels de suivi de la force bleue (SFB) utilisent le système de localisation GPS pour suivre séparément chaque soldat. Dans le cadre de deux expériences, nous avons étudié les effets du SFB sur le rendement du soldat au moyen d'une simulation informatique à la première personne. Au cours de la première expérience, 36 participants ont dirigé une section pour trouver et appuyer une autre force en contact avec l'ennemi. Ces derniers ont exécuté cette tâche au moyen d'une carte 2D avec un SFB précis, un SFB imprécis ou sans SFB. Les résultats ont indiqué que les soldats qui utilisaient le SFB avaient engagé le combat avec l'ennemi plus rapidement, mais que d'autres variables de rendement n'avaient pas eu une incidence importante. Ils avaient aussi utilisé leur carte plus fréquemment que ceux qui ne disposaient pas du SFB. L'utilisation du SFB imprécis n'a pas nui au rendement. Lors de la seconde expérience, les participants ont dirigé une base de feu dans le cadre de semblables missions d'attaque improvisée. Durant chaque mission, un événement unique pouvait influencer la décision d'attaquer. Les participants n'utilisaient pas le SFB ou bien utilisaient une carte 2D avec SFB ou encore trois affichages distincts à réalité augmentée. Le SFB pouvait avoir une précision des signaux de 100 % ou certaines imprécisions. Les résultats ont démontré que l'utilisation du SFB facilitait une détection d'événement plus précise et améliorait légèrement le temps de détection d'événement. Dans certaines conditions, un SFB précis a aussi entraîné une décision d'attaquer légèrement plus rapide. Par contre, cette décision n'était pas plus précise. La précision du SFB n'a pas eu d'incidence sur la capacité du participant de localiser et cartographier avec exactitude la position de la force bleue, mais elle a accru son niveau de confiance. Le SFB avec réalité augmentée n'offrait aucun autre avantage par rapport à un système cartographique de SFB. Nos études donnent à penser que le SFB favorise le rendement des missions, même lorsqu'il n'est pas tout à fait précis et que les systèmes de réalité augmentée offrent des avantages limités par rapport à un système cartographique portatif, du moins dans le cadre des tâches à l'étude.