Teamwork and Lethality in a Support by Fire Team

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ABSTRACT

To support the Army's long-standing efforts to understand, train, and improve squad lethality, our team conducted foundational research to identify and measure critical team behavior to evaluate their impact on performance measures and lethality in Army fire teams executing Battle Drill 2A (squad attack) during a day live fire event. Based on a review of existing literature and field training observations, we identified critical measures of teamwork and lethality as they relate to the support by fire (SBF) team. Squad teamwork behaviors were derived from team verbal communications using audio recording devices placed on each member of the team. Lethality measures included probabilities of hits and kills, target suppression, changes in firing rate over time, and distribution fire across the targets using location of miss and hit (LOMAH) sensors. The current paper examines the role of key team interactions including the type and timing of information shared on different measures of lethality. Additionally, the impact of demographic measures including time in service and record fire score are accounted for. Results from this study are being utilized to identify squad level measures of teamwork that are critical determinants of squad lethality for use in future iterations of squad performance models. Key takeaways for both the measurement of teamwork and lethality during live fire training and for improving a strategy for research on squad lethality are offered.

ABOUT THE AUTHORS

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Jacquelyn Schreck has an M.S. in Modeling and Simulation and a B.Sc. in Psychology with a focus on cognitive sciences, both from the University of Central Florida (UCF). She's worked in various human factors labs in the past and is currently a human factors intern at QIC while pursuing a Ph.D. in Modeling and Simulation.

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BACKGROUND

Lethality has become the primary benchmark to gauge the readiness and capability of infantry squads in the United States (U.S.) Army. This is evident given that Soldier lethality is listed as one of six priorities in the 2015 Army modernization strategy (U.S. Army, 2015) as well as the recent formation of the Close Combat Lethality Task Force in the Department. of Defense (South, 2019). Lethality is defined as the ability to incapacitate the enemy (e.g., Minisi, 2016) and is often described in terms of modernizing the Soldier's weapons. However, lethality can also be described from the point of view of an individual and a collective team. Although lethality at the individual level may provide insight into the skills that each Soldier brings to the fight, lethality of a team is not solely the compilation of individual performance. Rather, it is a multidimensional construct including both weapon capabilities and the ability of the collective unit to use fire and maneuver to incapacitate the enemy (Martin, Perez, Peterman, 2017). Therefore, the current study examines the role of team processes on the lethality of a support by fire (SBF) team during a squad live-fire event.

Research on teams in the military has shown that measurable team processes and states impact team performance (Mathieu, Heffner, Goodwin, Salas, Cannon-Bowers, 2000; Salas, Reyes, & McDaniel, 2018). For example, the Navy's tactical decision making under stress (TADMUS) program demonstrated that shared mental models and group cohesion contribute to better coordination and decision-making (Mathieu et al., 2000). Additionally, research has shown that training that focuses on developing team competencies like communication, coordination, and leadership improves team performance (e.g., Dwyer et al., 1999; Salas, Burke, Bowers, & Wilson, 2001). Johnston, Phillips, Milham, Riddle, Townsend, DeCostanza, Patton, et al., (2019) found that team dimensional training (TDT) improved the performance of infantry squads doing tactical combat casualty care (TC3) in the context of a complex mission during a live training event. They found squads demonstrated more TC3 and team knowledge emergence (teamwork and situation awareness) behaviors, and performed more complete after action reviews after receiving TDT than teams that did not receive the training.

While there is extensive research on team dynamics, team researchers have been calling for more field research on teams to advance our understanding of team development and team processes (e.g., Mathieu, Wolfson, & Park, 2018; Salas et al., 2018). This is especially true for teams in isolated, confined, and extreme (ICE) environments (Driskell, et al., 2018), which includes infantry squads. Research on team dynamics in infantry squads cannot easily be done in the laboratory and field research on team dynamics in squads during live fire training is non-existent. To try to fill this gap in our understanding we observed squad live fire training events to 1) identify and define the measures of team process and lethality that were most critical to mission success, and 2) develop a set of unobtrusive measures with which to collect them.

The participants were part of the support-by-fire (SBF) team in infantry squads executing the squad attack battle drill (BD) 2A as described in Army Training Publication (ATP) 3-21.8. (Headquarters, Department of the Army, 2016). By analyzing the verbal communication of the SBF team, we were able to identify elements of leadership, information exchange, and supporting behavior. Measures of lethality were derived from the effectiveness with which the team engaged the targets with live fire. These measures included the team's ability to distribute its fire effectively over time and across its field of fire as well as its ability to hit /kill targets.

Although this was an exploratory study, it was hypothesized, based on past research and theory, that better team processes would be associated with greater lethality. However, we did not know which of our measures of team process or lethality (if any) would be correlated. Furthermore, some of our measures were untested when we did this data collection. For example, we did not know how many rounds the Location of Misses and Hits (LOMAH) sensors would detect or if our approach to measuring team process would be sensitive enough to differentiate among the ability levels in our sample.

METHODS

Background

The squad attack battle drill may seem simple on paper, but it is in fact a very complex team task that requires considerable practice to master. To understand how this battle drill is executed, it is necessary to understand the organization of an infantry squad. The nine person Army infantry squad is divided into two, four person fire teams (A and B) plus a squad leader (SL), usually an E6 Staff Sergeant. Each fire team is composed of a team leader (TL), usually an E5 Sergeant, an M249 squad automatic weapon (SAW) gunner, a grenadier armed with an M320 grenade launcher (GRD), and a rifleman (RIF). The M249 is the most casualty producing weapon and it is usually assigned to the most senior member of the fire team after the TL, typically an E4 corporal or specialist.

In the squad attack battle drill, the squad has made contact with and is receiving fire from an enemy position with no more than 3 individuals (Headquarters, Dept. of the Army, 2016, ATP 3-21.8, pp. J-8 – J-10). The fire team that first makes contact (e.g., A Team) will take covering positions and return fire (see point 1 in figure 1). This fire team's role is to lay down suppressive fire to pin the enemy down, forcing them to remain under cover. With the enemy position suppressed, the SL will then maneuver with the other fire team (B Team) to a flanking position about 90º to the enemy's left or right relative to the A Team direction of fire (see point 2 in figure 1). The SL decides whether to flank left or right based on terrain.

Once in position, the SL will signal to the A Team leader to shift fire from the enemy position and away from the assaulting team (see dashed arrow near point 1 in figure 1). This is followed by a lift fire (cease fire) command just before the B Team begins the assault (see point 3 in figure 1). After lift fire, the B Team then assaults through the enemy position, followed by the A Team. After securing the perimeter and searching/assessing casualties, the drill is over.

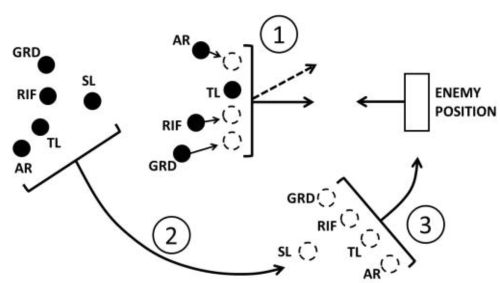

Figure 1. Depiction of the components of BD2A that were part of this data collection. This data collection began at point (1) when the SBF team made contact with the enemy. It continued through point (2) the flanking maneuver of the B Team, and ended at point (3) when the B Team began its assault on the enemy position.

The focus of this study is the performance of the A Team from the moment of contact until the lift fire command was given. This is a period of intense teamwork. Team members must call out contacts and magazine changes and malfunctions. These key pieces of information provide ongoing team situational awareness of who is able to engage targets. Team members use this information to adjust their individual rates of fire insuring all targets are engaged and that a sufficient volume of fire is maintained, a process called *talking the guns*. The TL should monitor rates of fire and command the team to adjust fire as needed. Finally, team members echo key commands from the TL to insure the command is heard all the way down the firing line over the intense sound of live fire.

Pilot Study

Between February 2019 and February 2020, we supported a pilot project focused on squad performance sponsored by the U.S. Army's Program Executive Office (PEO) Soldier. The overall objective of this pilot project was to examine the feasibility of creating a standardized evaluation protocol that could be used to determine the impact of new materiel solutions on squad performance. This pilot project provided a rare opportunity to collect data from a large number of infantry squads executing a series of live training events.

By August of 2019, we had observed five iterations of this pilot project. In each iteration, between four and six infantry squads spent a week conducting a variety of individual and collective tasks during the day and at night. The exact protocol changed in small and large ways with each iteration as PEO Soldier was experimenting with different methods. During this time, we worked with the PEO project team to develop and pilot our measures of team performance (see descriptions below). Our expectation was that once the protocol stabilized, there would be continuing opportunities to measure squads. As it turned out, the final iteration of this project was scheduled to take place with 18 squads from the same unit in February 2020. The data reported here are from those 18 squads.

The data collection protocols of both PEO Soldier and our research group were determined to be exempt by the Army Research Laboratory Human Research Protection Office (ARL determination 19-118, and 19-201 respectively).

Equipment

Digital audio recorder. To collect audio recordings, a Tascam DR 40X four track digital audio recorder (tascam.com) was placed inside of a FirstSpear MultiMag Rapid Adjust™ magazine pouch (first-spear.com) and attached to the webbing worn by the Soldiers. The magazine pouch could be easily tightened to ensure the audio recorder was firmly held. The digital audio files were analyzed for both voice and rate of fire. For verbal communications, the audio files were manually transcribed. The speaker for each communication was identified and time stamped relative to the moment the squad made contact with the enemy. Transcripts ended when the lift fire command was given.

To determine rates of fire (RoF), a software script was developed to identify peaks in sound intensity that were indicative of the firing of live ammo at close range. Using this technique it was not possible to distinguish between individual M4s but it was possible to distinguish between fully automatic and semi-automatic fire. All recordings were analyzed by a MATLAB® script that lined up recordings from the entire squad so that it could avoid counting duplicate rounds. The output of the script was a timeline for all SAW vs non-SAW shots. This allowed us to monitor changes in rates of fire throughout the event. It should be noted that we could not determine rates of fire of training munitions using audio recordings due to the low intensity sound from those munitions.

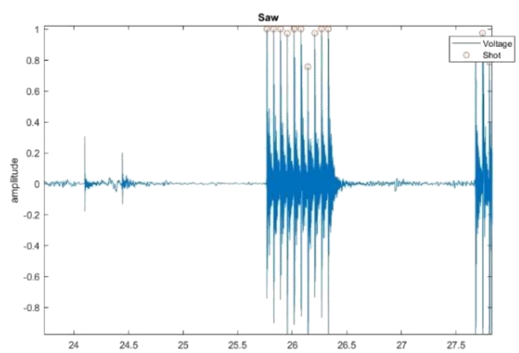

Figure 2. Graphical depiction of audio file showing voltage amplitude and detected shots (red circles). This burst lasts approximately 0.6 seconds and contains 10 shots.

Figure 2 illustrates a burst of fire by the SAW gun from an audio file and the peaks/shots that were identified by our software script. The SAW is fired in short bursts during which the firing rate is about 850 rounds per minute. As can be seen in this figure, we were able to distinguish individual shots from a single bust using digital audio recorders. Weapon mounted inertial sensors were not used to determine rates of fire due to concern over the safety of attaching unfamiliar items to the soldiers' weapons.

Targets. Three Marathon targets (marathon-targets.com) were used for this event. The Marathon targets were programmed to pop-up as the squad approached the objective and then move towards the firing line to predetermined positions about 100m from the SBF line. From the firing line, the right side target (target 3) was closest to the firing line, the left target (target 1) was farthest away and the middle target (target 2) was an intermediate distance from the firing line. The reason for this echelon right formation (from the targets' perspective) was that the terrain was most ideal for a left flanking maneuver by the assaulting team.

These targets provided counts of critical and non-critical hits. Critical hits are those that occur in the head, neck, and center trunk. All other hits are non-critical. The targets were programmed to drop after one critical hit or three non-critical hits. After each "kill", the targets were raised again after seven seconds and kill criteria were reset. The targets faced the SBF position until the shift fire command was given. At that point, the targets pivoted in place to orient in the direction of the assaulting team. The Marathon targets were used by PEO Soldier and this data was provided to us under a data sharing agreement.

LOMAH Sensors. To collect the dispersion of rounds fired at the targets, three LOMAH sensors were placed behind a small earth berm about 30 feet in front of each of the three Marathon targets. LOMAH sensors pick up shock waves produced by supersonic rounds and triangulate the x, y coordinates of rounds as they pass a plane above the sensor. The sensors were configured to detect rounds passing through a 5 meter wide by 2.5 meter high window.

The LOMAH sensors were placed so that they lay directly in the line of fire from the center of the firing point of the SBF team. The LOMAH sensors were connected to digital radio relays that transmitted to a gateway receiver in the assembly area where the researchers were located. The gateway receiver was attached to a Toughbook running Targetry Range Automated Control and Recording (TRACR) software. TRACR collates the sensor data for each session. Before each squad began, we verified that all sensors were reporting on the network, however there were three squads from which we were not able to get any usable LOMAH data.

We had hoped to use the LOMAH sensors to get a picture of the overall distribution of fire around the targets, not just the hits which were detected by the targets themselves (see below). As it turned out, the LOMAH sensors detected 59.7% of all shots fired. We think this was due to the fact that a) the 30ft distance between the target and sensor made it difficult to align the sensor's window with fire coming in from the entire span of the SBF position, and b) the detection window may have been too small to detect all of the shots going downrange.

Summary of Measures. Table 1 below, summarizes all the lethality and team process measures that were collected from the three sources of data in this research effort (audio, LOMAH, and targets). It is worth noting that we did not have any way to link individual shooters with the target data, so we could not determine the hit or kill rate per shooter. Those metrics could only be determined at the team level. Team process measures were based on the team dimension training framework (e.g., Johnston et al., 2019). Some measures like "Word Count", were more objective than others (e.g., "Closed loop responses"). For measures which are less objective, two to three raters assessed the counts independently using pre-determined definitions. Although infrequent, count discrepancies among the raters were resolved by discussing the specific incidences to check if definitions were applied consistently in order to arrive at a consensus count.

Table 1. Summary of Dependent Measures

Construct	Description
Lethality Measures	
Accuracy	• Probability of Hit (PH) = #target hits/#shots fired by team (overall & per target) • Probability of Kill (PK) = #target kills/#shots fired by team (overall & per target) • Total Hits = total number of hits (overall & per target) • Total Kills = total number of target kills (overall & per target) • Percent suppression time = percent of time (from contact to shift fire) the targets are suppressed. Targets are suppressed for 7 seconds following a kill. (overall & per target) • Critical hits = total number of critical hits (overall & per target) • Non-critical hits = total number of non-critical hits (overall & per target)

Volume of Fire	• Total rounds expended = rounds given per member – rounds remaining at end of exercise (overall & by position) • Total rounds fired = round count from audio file (SAW & M4s) • Rate of Fire over time = rounds fired per minute (SAW & M4s) • Rounds per LOMAH = rounds counted by LOMAH sensors (overall & per sensor/target) • "Talking the "Guns" (TG ratio) = 1 - ($\frac{Drill\ time\ with\ "dead\ space"}{Total\ drill\ time}$)
Team Process Measures	
Leadership	• Team Leader (TL) Flanking = (0-no /1–yes). The TL should notify the team which direction the B Team is flanking when notified by the squad leader (SL) • TL Shift = (0-no /1 –yes). The TL should issue the shift fire command when notified by the SL • TL Lift = (0-no /1 –yes). The TL should issue the lift fire command when notified by the SL. • TL firing rate - the no. of times TL directed the firing rate of a Soldier or the whole team.

Information Exchange	• Team DDD (description, distance, direction) = No. of DDD Events/Total No. of Possible DDD Events (#team members*3)
	• Team Flanking = No. of Flanking Events/Total No. of Possible Flanking Events (#team members)
	• Echo Shift = No. of Shifting Events/Total No. of Possible Shifting Events (#team members)
	• Echo Lift = No. of Lifting Events/Total No. of Possible Lifting Events (#team members)
	• Self-update report rate= (Reload updates + Malfunction updates) / (Reloads + Malfunctions), where:
	  o Reload updates – the number of times team members announced the reload was complete
	  o Malfunction updates – the number of times team members announced they had cleared their malfunction.
	  o Reloads – the number of times team members announced they were reloading
	  o Malfunctions – the number of times team members announced they had a weapon malfunction
	• Others' Help response rate = (Got you covered) / (Reloads + Malfunctions), where:
	  o Got you covered – the number of times other team members responded to a malfunction or reload with "Got you covered" (or similar)

Communication quality	• Word Count (Individual/Total) =Total words spoken. • Unique Words (Individual/Total = total count of unique words. Fewer unique words reflects greater consistency in communications. • Closed Loop Responses = total count for team (e.g., "roger"). Closed loop responses reflect proper communication protocol. • Non-Essential words = total count for team. Fewer non-essential words reflect better communication behavior.

Participants

Participants were 47 fire team members from 18 squads from the same U.S. Army unit. Squads arrived in four different groups at two day intervals. The first two groups included four squads each and the last two groups included five squads each. Squads brought their own weapons and equipment to include day and night optics, radios, and ballistic armor.

The experience level of the team members varied by position. As would be expected, the team leader had significantly more time in service, averaging 45 months, than the rest of the team members who averaged 17 months or less ($F(3,58) = 11.89$, $p<.01$). The SAW gunner was typically the next most senior, followed by the rifleman and the grenadier although these times were statistically indistinguishable. When looking at time in grade, in position, and in the squad, there were no significant differences across team members (see Figure 3).

Of the 18 teams we examined, 11 included all four members and seven were missing one member. Of those seven, three were missing a rifleman, three others were missing a grenadier, and in one team, the TL operated the SAW. The presence of incomplete teams was a common occurrence and so we decided to include data from incomplete team. In an operational environment, teams still have to perform their missions even if they are not at full strength.

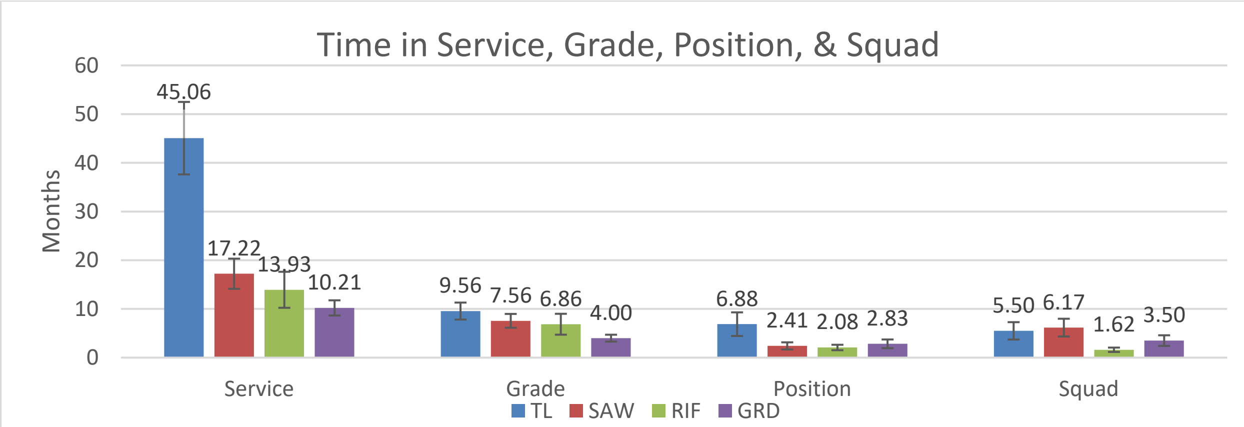

Figure 3. Time in Service, Grade, Position, and Squad by Position.

Procedure

Squads in-processed and completed demographic questionnaires administered by the PEO Soldier Team. The demographic data presented in this report includes months in service, grade, position, and squad. This data was provided to us under a data sharing agreement with PEO Soldier. Note that in the three weeks prior to arriving, each of the squads spent four days in a train up event at their home station.

On day two, squads confirmed zero on their weapons on a live-fire range and then practiced BD-2A using training munitions. Squads were provided with the training munitions and specialized bolt carrier assemblies. In the practice runs, the observer controllers (OCs) verified that each squad was able to safely conduct BD-2A using live fire. To minimize practice effects, squads were allowed a maximum of four practice runs before being disqualified for using live ammo. Of the 18 squads, one fire team was required to conduct the battle drill using training munitions.

Once each squad was certified to complete the BD-2A assessment, they proceeded to an assembly area next to the designated live-fire range. There, they were issued ammo, given a safety briefing and conducted their pre-combat checklists. The SAW gunners were given three, 200-round plastic drums with linked 5.56 ammo and the remaining squad members were given seven, 30-round magazines. Grenadiers were also given three M320 training rounds. After receiving ammo, our team attached one digital audio recorder to the webbing of each member of the A Team.

The squads were not familiarized with the terrain used for the live fire assessment. Just prior to the time the squad and OCs entered the range, a data collection session was started on TRACR. About five minutes after entering the range, squads made initial contact with the targets. The mean time interval from contact to shift fire was 3.83 min. ± 15.5 sec. The mean interval from shift fire to lift fire was 1.48 min. ± 14.3 sec. After the squads completed the exercise and exited the range, our research team retrieved the audio recorders. Squads turned in magazines and any unspent ammo.

RESULTS

In the first two sections of the results we summarize the team process and lethality findings so that the reader understands how the performance of the fire teams in our sample is reflected in these measures. Since there is only one group, these first two sections primarily serve to characterize the sample. In the third section, we evaluate our hypothesis by examining the correlations between team process measures and lethality measures.

Team Processes

<u>Leadership and Information Exchange</u>. Both leadership and information exchange communications fell into two categories: procedural and event related. Procedural communications occur at certain key points in the battle drill. They are a known quantity and so we scored them in terms of a percent of instances that they occurred. A proficient squad should do all of these 100% of the time. Event related communications occur in response to unpredictable events (like a weapon malfunction) that can occur. These were scored as frequencies.

Table 2. Frequency of Procedural Communications

	Information Exchange				Leadership Communications		
	DDD	Echo Flanking	Echo Shift	Echo Lift	Flanking	Shift	Lift
Mean	0.52	0.59	0.85	0.81	0.82	1.00	1.00
SEM	0.07	0.10	0.05	0.08	0.10	0.00	0.00
$t(17)$=	-6.43	-4.14	-2.85	-2.33	-2.20	-1.00	-1.00
$p\leq$	.01	.01	.01	.05	.05	ns	ns

Table 2 summarizes the procedural communications by the team leader and team members. For example in the two right most columns, you can see that the TL always called out shift and lift commands. This is not particularly surprising as these commands are essential to avoid fratricide. One sample t-tests revealed that all team information exchange was done at rates that were significantly less than 100% as was the team leader's announcement of the direction of the flanking maneuver.

Table 3. Frequency of Event Related Communications

	TL Firing Rate	Malfunc-tions	Malfunction updates	Reloads	Reload updates	Got you covered	Self update report rate	Others' help response rate
Mean	8.71	0.94	0.22	4.22	1.17	0.39	0.33	0.10
SEM	1.09	0.45	0.13	0.52	0.28	0.20	0.08	0.02

Six event-related communication measures were assessed, and two additional measures were derived from specific measures. These two measures pertained to the extent to which the team member updated the rest on the weapon status whenever s/he reported a malfunction or reload (i.e., Self Update report rate), and the extent to which other team members initiated help whenever a team member's weapon was down from a malfunction or reload (i.e., Others' Help response rate - Table 3). The one-sample t-test revealed that the team members did not do either of these consistently. For Self Update report rate, $t(16)= -19.07$, $p<.001$, and for Others' Help response rate, $t(16)= -10.63$, $p<.001$. As for how frequently the team leader directed the team on firing rate, it was found that this varied rather widely across squads (i.e., range was between 5 and 20).

Table 4. Word Counts

	Total	Unique	Non-Essential	Closed-Loop	TL	SAW	RIF	GRD
Mean	154.39	133.22	9.11	12.50	109.11	19.56	16.28	9.44
SEM	20.96	16.91	2.53	1.72	16.49	3.08	3.80	2.57

Communication Quality. Large variability across squads was also observed in the number and type of words exchanged across teams (e.g., total, unique, non-essential, closed-loop). Mean word counts spoken by each team member differed significantly, $F(3,68) = 29.46$, $p<.01$. The TL uttered significantly more words (66% of all words spoken) than the other team members (Table 4).

Lethality Metrics

As described above, the concept of lethality for a team is complex. There is no single or standard measure of lethality for a support by fire team. The lethality of the support by fire team is related to its ability to suppress and fix the enemy while the assaulting team moves into a favorable position for an attack (Headquarters, Dept. of Army, 2016, ATP 3-21.8, p. 1-41). In order to suppress the enemy, the SBF team must maintain a sufficient volume of fire in the direction of the enemy position. However, this same volume of fire reduces traditional measures of lethality like probability of hits or kills. For this reason, our measures of lethality fall into two main categories: volume of fire and accuracy of fire.

Volume of Fire. As mentioned, where volume of fire is concerned, more is not necessarily better. The SBF team is expected to initially engage the enemy with a cyclic or rapid rate of fire progressing to a sustained rate of fire. The rate of fire needs to be sufficient to suppress the enemy without wasting ammo or barrels (Headquarters, Dept. of the

Army, 2016, ATP 3-21.8, p. F-22). As the results above show, the majority of the TL's communications are focused on controlling the team's rate of fire which reflects the importance of this task. First, we look at rounds expended by position, then the rates of fire over time, the synchronization of rates of fire between the SAW and the M4s, and finally the "Talking the Guns" measure.

The SAW gunner, not surprisingly, expends significantly more rounds than any of the other team members by a considerable margin ($F(3,52) = 11.66$, $p<.001$) (see Table 5). However, in the aggregate, the combined volume of fire of the M4s approximates that of the SAW gun (243.43±34.05 vs. 213.93±29.68). So, while the SAW is the single most casualty producing weapon, collectively, at least in our data set, the M4's produced a similar volume of fire.

Table 5. Rounds expended by position

	TL	SAW	GRD	RIF
Mean	57.38	199.88	78.55	71.31
SEM	5.84	32.69	12.42	11.28

Next, we consider rates of fire over time. These were determined from the audio files starting with initial contact until the shift fire command was given. Rate of fire data was available from 13 of the 18 teams. Because the duration of this interval varied for each team, rates of fire were measured from progressively fewer teams over time. Figure 5 shows the number of squads engaged in the drill in each minute and the average rate of fire from the SAW and M4s still firing in each minute. Most squads had completed the drill before the seventh minute mark after initial contact. This attrition makes any statistical analysis of these data difficult. However, we present them here so that we can examine rates of fire against Army training doctrine.

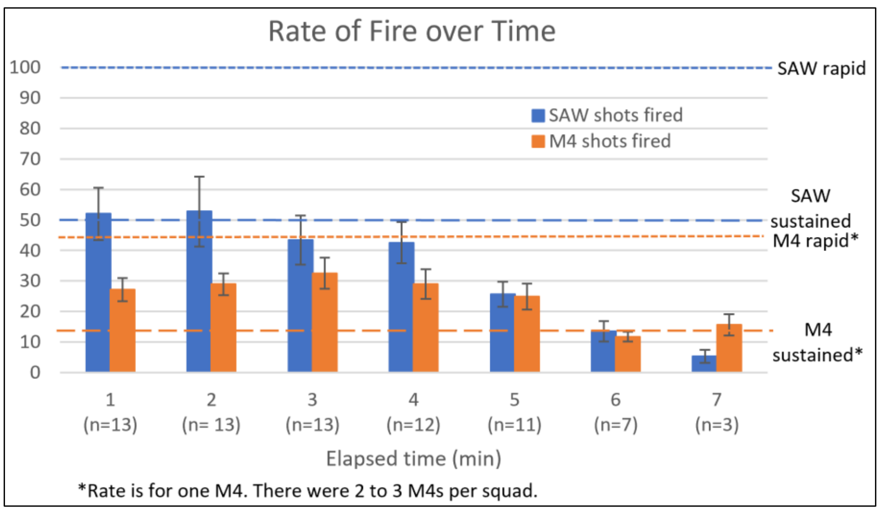

Figure 5. Rate of fire over time (Error bars denote standard errors).

When looking at rates of fire over time, it can be seen that on average, the SAW gun managed about 40 to 50 rounds per minute for the first four minutes after contact and this dropped to about 25, then around 15 or fewer rounds per minute for the last two minutes (Figure 5). For the SAW gun, the rapid rate of fire is 100 rounds per minute and the sustained rate of fire is 50 rounds per minute (Headquarters, Dept. of the Army, 2017, TC 3-22.249, p 8-4). So, for the first four minutes, the SAW gunners maintained a sustained rate of fire, and by the last few minutes they were firing at less than half the sustained rate.

For an M4, rapid fire is 45 rounds per minute and sustained fire is 12-15 rounds per minute (Headquarters, Dept. of the Army, 2017, TC 3-22.9, p 8-6). For a fire team with three M4s, the necessary rate of fire would be 135 rounds per minute for rapid fire and 36-45 rounds per minute for sustained fire. Even if squads only have two M4's in action, they should adjust their rates of fire to accommodate for the missing gun. In our data set, the M4's collectively maintained an average of 27-33 rounds per minute for the first four minutes and this dropped to 20 rounds or fewer per minute by the last two minutes, so their rate of fire was consistently below the sustained rate of fire (for three M4s). In summary, these fire teams were conservative in their expenditure of ammo in the first minute when their rate of fire should have been in the rapid fire range. The SAW gunners were conservative throughout the exercise shooting below a sustained rate of fire in all but a couple of minutes at the beginning of the drill.

In addition to seeing the distribution of fire over time, the LOMAH sensors give us the ability to see the distribution of fire across the entire field of fire. Each LOMAH sensor was positioned in front of a target and by looking at the number of rounds detected by each sensor, we can see how the fire team was distributing its volume of fire across the three targets. The data in Table 6 shows that target 2 (the center target) had significantly more LOMAH detections, $F(2,40) = 8.43$, $p<.01$, than the other two targets. This indicates that the teams were not distributing their fire equally across all three targets.

Table 6. Rounds detected by LOMAH, Hits, and Kills per Target

	Target 1 (Left Side)		Target 2 (Center)		Target 3 (Right Side)	
	Mean	SEM	Mean	SEM	Mean	SEM
LOMAH	33.53	7.45	110.47	16.78	58.08	15.76
Hits	3.00	1.01	21.88	2.36	15.50	2.58
Kills	1.44	0.55	8.88	1.17	6.50	1.13

<u>Accuracy of fire</u>. Similarly, we can look at target data to see the average number of hits and kills per target. As Table 6 also reveals, the distribution of hits and kills parallels the distribution of LOMAH data across targets. Target 2 (the center target) had significantly more kills than the other two targets, $F(2,45) = 14.81$, $p<.01$, and significantly more hits, $F(2,14) = 19.20$, $p<.01$, than the other two targets. Target three (right side) also had significantly more hits than target one (left side). Together with the LOMAH data, the hit and kill data per targets shows that the fire teams did not engage all of the targets equally despite the fact that all the targets were equally exposed throughout the exercise.

<u>PH and PK.</u> When looking at the combined data from the three targets, you can see that the teams averaged about 26 non-vital hits and 17 vital hits. This gave them a probability of hit (PH) of 17% and a probability of kill (PK) of 6%. Because the targets were down for about seven seconds each time they were killed, they were suppressed for a total of about 117 seconds, which translates to about 17% of the total time on average from contact till the shift fire command was given. Although the PH and PK seem very low, it is important to remember that the role of the SBF team is to suppress by fire by maintaining a volume of fire over the enemy position, even if the enemy is not exposed. As was noted above, maintaining a high volume of fire will lower these traditional measures of lethality.

Table 7. Target Data

	Non-vital hits	Vital hits	Tot suppression time (sec.)	Suppression Percent	Probability of Hit	Probability of Kill
Mean	25.69	16.63	117.69	17.72	0.17	0.06
SEM	3.11	1.77	12.11	2.27	0.03	0.01

<u>"Talking the Guns" (TG ratio)</u>. This measure pertains to the proportion of active drill time where firing activity among the weapons were synchronized and collectively generated suppressive fire. The TG ratio for the teams in the dataset ranged from 0.14 to 0.43 (*M*=0.26, *SE*=0.02).

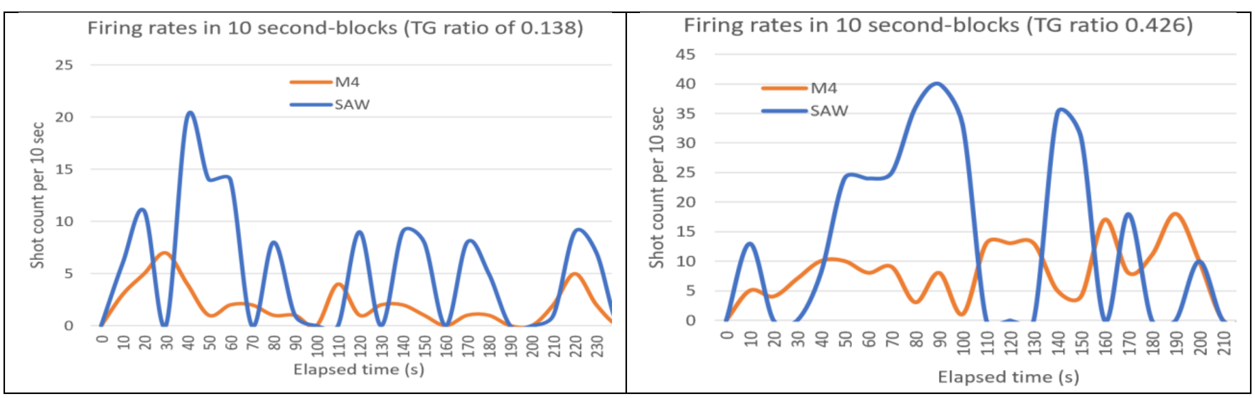

Figure 6. Squads with the highest and lowest TG ratios (rate of fire as rounds per minute)

In the left panel of figure 6, you can see that the M4s and the M249 were increasing and decreasing their rates of fire in synchrony. This meant that there were a lot of blocks of time when nobody was firing their weapons. Those pauses in firing would provide opportunities for the enemy to return fire or maneuver. In the right hand panel of figure 6, you can see that the M4s clearly picked up their rates of fire when the M249 was down, maintaining a steady volume of suppressive fire throughout the exercise. By talking their guns in this way, the SBF team would pin the enemy down while the assaulting team maneuvered into position.

Relationship Between Lethality, Team Processes and Experience

To examine the relationships of lethality, communication, and experience, we looked for significant correlations among these measures. Because of the large number of comparisons, we only considered correlations that were significant at the $p<.01$ level.

Several lethality measures were significantly correlated: Number of SAW shots with LOMAH shots ($r=.925$, $p<.01$), and with Average Rate of Fire ($r=.831$, $p<.01$). Number of M4 shots with LOMAH shots ($r=.885$, $p<.01$), and with Average Rate of Fire ($r=.724$, $p<.01$). As would be expected, there were positive signification correlations between the "Talking the Guns" (TG ratio) measure and average rate of fire from the SAW ($r=.906$, $p<.01$) and M4 ($r=.950$, $p<.01$).

Significant correlations were seen between the rounds expended by all and word count by the team ($r = .638$, $p<.01$), and unique words ($r = .682$, $p<.01$). Likewise, there were several significant correlations between the number of rounds expended by the rifleman and communication measures: word count ($r=.760$, $p<.01$), unique words ($r=.838$, $p<.01$), team leader word count ($r=.709$, $p<.01$), team leader to squad leader word count ($r=.709$, $p<.01$), and malfunction updates ($r=.818$, $p<.01$). It is possible that communications served to trigger and reinforce greater number of rounds expended, however further examination of the communication content is needed to determine the nature of these relationships.

The experience measures of some squad members seemed to be positively associated with the rounds fired by other squad members. For example, the rounds fired by the SAW was positively correlated with both the time in grade ($r=.828$, $p<.01$), and the time in squad of the rifleman ($r=.805$, $p<.01$). The rounds expended by the rifleman was positively related to the time in squad of the grenadier ($r=.896$, $p<.01$). The reason for theses associations is not clear, but it may reflect some kind of indirect influence across team members that we are unable to see in our data.

DISCUSSION

The data collected unobtrusively from audio recorders, LOMAH sensors, and targets enabled us to provide a rich empirical characterization of the performance of these squads to include team processes and measures of lethality. Although the final sample lacked the range of skill levels that would have made it possible to tease apart the relationships between these two sets of measures, we believe that the data presented represent a critical first step towards a more objective scientific study of this ICE environment team.

In general the infantry squads included we analyzed were relatively new and inexperienced. This was reflected in the short time in service, position, and squad of most team members. It was also reflected in measures of both teamwork and lethality. For example, calling out target DDD, reloads and malfunctions enable all team members to maintain situational awareness of critical information. Some of our measures indicated that teams struggled to share this information as frequently as they should have. For example, calling out target DDD was only done 52% of the time and echoing the flanking direction was only done 59% of the time. Team leaders also made mistakes. For example, they called out the flanking direction only 82% of the time. This is an important piece of information that enables the team members to have situational awareness of which side of their field of fire their squad mates are on.

Communications about weapon status also seemed deficient. Based on the total number of rounds expended, we would expect about seven to eight magazine changes across the squad on average, but squads called out magazine changes only four times on average and updates on reloads and malfunctions occurred only 33% of the time.

Turning to measures of lethality, the squads did not lay down a sufficient volume of fire during the first minute of the exercise. The initial minute should consist of mostly rapid fire (e.g., 100 rounds/min./SAW and 135 rounds/min./3

M4's) but on average squads fired at half this rate, approximating a sustained rate of fire, or slower. This slower rate of fire continued for the duration of the exercise. Regarding the lateral distribution of fire, squads clearly focused their fire on the center target. Based on the LOMAH data, this target received about double the volume of fire of the other two targets. All three targets were equally exposed throughout the exercise.

Our data do not provide a clear explanation for why the center target received so much more fire. As noted earlier, teams were only calling out targets about half the time, and so it is possible that this degraded the team's situational awareness leading to neglect of the lateral targets. However, team members should have had a relatively unobstructed view of all three targets from the firing line. One final hypothesis is that if the center target was more salient to them, the stress of live fire may have diminished their ability to attend to the less salient targets on the left and right (Sänger, Bechtold, Schoofs, Blazkewicz, & Wascher, 2014).

Regarding lethality, measures of accuracy indicated that about 14% of all shots resulted in hits and 6% resulted in kills. The total duration of time each target was down was about 17% of the total time before the shift fire command was given. Though these seem like low percentages, in the absence of an Army standard or any normative data, we have no way to evaluate these lethality measures as being at, above, or below expectations. This highlights the need for the Army to conduct research and analysis to determine such standards.

Related to this is the realism of the targets' behaviors. Typically an enemy would seek cover/concealment and would attempt to minimize their exposure by coming out of cover only enough to take a shot. Furthermore, just the sound of a round passing nearby will cause most people to seek cover rather than remain in an exposed position. More realistic target behavior would simulate true suppression, make target detection much more difficult, would necessitate more frequent communication about target locations, weapon status, etc., and would potentially provide more realistic training for a support by fire mission.

In contrast to prior work (e.g., Johnston et al., 2019; Mathieu, et al, 2000, Salas, Reyes, & McDaniel, 2018), we saw only hints of a relationship between team processes and performance. More communication was associated with a greater volume of fire. Volume of fire as assessed by shots fired and rounds expended was also related to the TG ratio, which, by its definition, better serves the key performance objective of the A Team in BD2A since it entails the distribution of shots over the active drill duration that would result from coordination of firing activity. The weakness of associations between team processes and lethality is not too surprising given the sample we had. When we first began this effort, we anticipated being able to collect data from a wide range of skill levels. Unfortunately our sample is comprised of a fairly homogenous set of teams, all from the same parent unit, possibly resulting in some range restriction that impacted the correlations. Furthermore, these teams were all relatively young and inexperienced. The average time in grade, position, and squad for all team members was well under one year. Aside from the team leader, team members averaged less than a year and a half in service. As our data seem to indicate, this inexperience was reflected in measures of information exchange and leadership.

In conclusion, understanding the relationship between team processes and lethality at all echelons will help the Army to better train and assess effective combat units. Despite the limitations of this research, this study is the first to attempt to quantify this relationship in an infantry squad during a live fire event; however, much more research is needed to fully understand this complex relationship. Importantly, we feel that there are several lessons learned from this research:

- Now that we have shown we can generate objective measures of performance in a live fire evet, a much wider range of squads at different skill levels needs to be evaluated during BD 2A live fire. Being able to document differences between expert and novice teams will provide a much stronger test of the dependency of lethality on team processes, it will also help us to understand how squads develop into expert teams.
- Target behavior needs to be more realistic. It is possible to instrument targets to react to near misses and to have more realistic exposure times. Realistic target behavior will provide better feedback to the SBF team on their effectiveness and will present a more challenging target requiring better information exchange and coordination of fires among team members.
- Army training and doctrine developers need to support establishing more objective standards and measures of performance for the infantry squad. Current Training and Evaluation Outlines rely mostly on subjective assessments but as we have shown, current technologies allow us to collect measures that are highly relevant to squad performance and lethality. Standards need to be established for volume of fire over time and across targets as well as acceptable PH, PK, and TG ratios for teams and squads under various conditions.

- Finally, it will be necessary to evaluate the entire squad across a range of battle drills. We will be pursuing both of these objectives as part of the Small Unit Performance Analytics (SUPRA) project sponsored by Combat Capabilities Command Soldier Center in FY21-22.

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