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14. ABSTRACT
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TOPOLOGY AND INDIVIDUAL LOCATION OF CROWDS AS MEASURES OF EFFECTIVENESS FOR NON-LETHAL WEAPONS

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ABSTRACT

A quantitative analysis method for crowd responses to non-lethal weapons (NLWs) has been developed. Using motion capture technology, the location and orientation of all individuals in a crowd were recorded during various engagements with a control force wielding simulated NLWs. The motion and behavior of the group, both as a whole and as individuals, were quantified using a variety of metrics derived from these measures. Several of the proposed metrics (average leading edge and streamlines) were sensitive to differences in critical characteristics of the scenario, such as weapon type (standoff vs. hand-to-hand combat) and rules of engagement (threat vs. no threat). Therefore, these metrics can be used to assess and compare effectiveness of different types of non-lethal weapons and systems and how weapon effectiveness varies with tactics, techniques, and procedures.

INTRODUCTION

Crowd management may be the prototypical military scenario that requires the use of non-lethal weapons. To prevent and manage possible crowd disturbances, non-lethal weapons need to be developed with tactics, techniques and procedures (TTP) for employment. However, to accomplish this goal, there must be a way to judge the effectiveness of different non-lethal weapons. Judgment of effectiveness requires understanding of both the behaviors that the war-fighter wants to induce using a non-lethal weapon and the crowd behaviors that will result from weapon use. To the first point, an examination of commands typically given to crowd members involve controlling their whereabouts—"Stay back!", "Leave!", or "Stay!". Therefore, the effectiveness of a non-lethal weapon should be based on how well the use of the weapon or TTP controls the location and movement of crowd members.

Decisions of the effectiveness of non-lethal weapons in crowd situations require methods to measure crowd response to non-lethal weapons. Then these measures can be compared against these desired responses. In other words, the primary question of effectiveness is: "did the crowd do what the Soldier wanted them to do when the weapon or TTP was used?" Then the question of comparative effectiveness becomes: "does one weapon or TTP accomplish this better than another?"

Metrics of crowd responses are necessary in order to conduct analyses comparing effectiveness of one non-lethal weapon or system with another. An exploratory series of behavioral experiments were undertaken to fulfill this requirement. The goal was to develop methods that describe critical crowd behavioral response relevant to the military's mission, namely location, orientation, and locomotion of persons in the crowd.

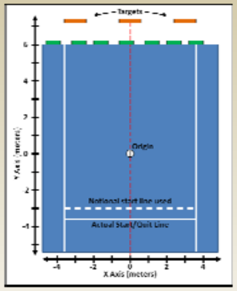
This paper describes the mathematical methods investigated to quantitatively describe crowds, group behavior of the crowd, and individual locomotion within the crowd. These methods are fundamental to the analysis of effectiveness of non-lethal weapons in crowd scenarios.

CONCEPTUAL FRAMEWORK

The Target Behavioral Response Laboratory (TBRL) program of Crowd Behavior research utilizes the Field Theory as expounded upon by Kurt Lewin (1935, 1936), as a framework that guides design, conduct, and analysis of experiments. Predictions of the areas or goal regions to which people move can be made based on the tenets of field theory.

SETUP

The human subjects were given a task of throwing a beanbag into one of three available targets that were placed on the opposite side of the testbed. Beanbags were numbered with the subjects' numbers. After each trial, researchers recorded whether a subject's beanbag hit the target, missed the target, or was not thrown. To increase their motivation, the subjects were given points if they were able to get their beanbag into a target. This task by itself was shown not to be very difficult.



METHOD

Conditions:

- Single Control Force, hand-to-hand weapon, threat ROE
- Single Control Force, hand-to-hand weapon, no-threat ROE
- Single Control Force, projectile weapon, threat ROE
- Single Control Force, projectile weapon, no-threat ROE
- Baseline, no control force

The crowd members were each given one beanbag. If the subject could get the beanbag into any of the targets at the far end of the field then the group was rewarded with points and money. Individual points were also tracked with bonus money for the individual with the best score. The scenario was designed to induce subjects to go towards targets and to go away from the control force.

Patterns of locomotion were expected to differ depending on the type of weapon (hand-to-hand vs. stand-off) and the simulated ROE (threat vs. no threat). It was expected that the threat condition would induce a much larger repulsive force than the no-threat condition. The no-threat condition was expected to have some level of effect due to the presence of the control force, even though the weapons were not employed. The hand-to-hand weapon was anticipated to have less repulsion than the stand-off weapon due to the shorter range of the hand-to-hand weapon.

MEASURES & METRICS

Recorded:

$X_{t,S}$, $Y_{t,S}$, $\theta_{t,S}$, where t is the time step and S is an individual subject from a set of N total subjects.

Individual Measures:

Distance traveled $$D_{t,S} = \sqrt{(X_{t+1,S} - X_{t,S})^2 + (Y_{t+1,S} - Y_{t,S})^2}$$

Velocity $$V_{t,S} = \frac{D_{t,S}}{\Delta t}$$

Interpersonal Distance $$ID_{t,Sa,Sb} = \sqrt{(X_{t,Sa} - X_{t,Sb})^2 + (Y_{t,Sa} - Y_{t,Sb})^2}$$

Control Force Distance $$CFD_{t,S} = \sqrt{(X_{t,S} - CFX_t)^2 + (Y_{t,S} - CFY_t)^2}$$

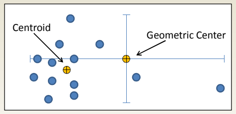
Radius (from group center) $$r_{t,S} = \sqrt{(X_{t,S} - C_t)^2 + (Y_{t,S} - C_t)^2}$$

Crowd Measures:

Geometric Center $$GC_t = \left(\frac{\max(X_t) + \min(X_t)}{2}, \frac{\max(Y_t) + \min(Y_t)}{2}\right)$$

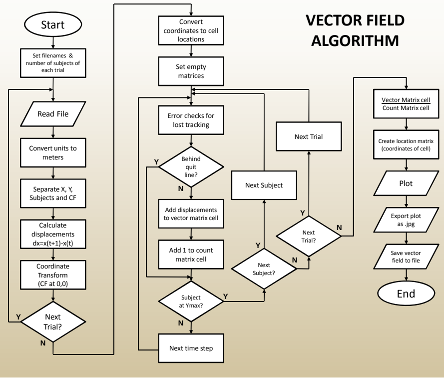
Centroid $$C_t = \left(\frac{\sum_{S=1}^{N} X_{t,S}}{N}, \frac{\sum_{S=1}^{N} Y_{t,S}}{N}\right)$$

Dispersion $$\overline{R_t} = \frac{\sum_{S=1}^{N} r_{t,S}}{N}$$



VECTOR FIELDS

The movement data captured in this study was also used to see if Lewin's Field Theory of behavior could be used to understand an individual's real movement toward a positive valance goal and away from a negative valance goal. The data from each individual subject was processed to create vector field maps of the topology presented in the experimental situation.

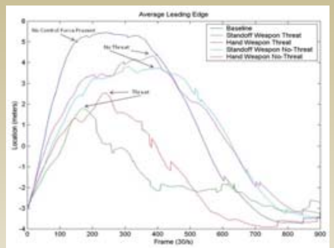


RESULTS & DISCUSSION

This experiment investigated how the behavior of a crowd or group of multiple individuals could be expressed numerically. The data set used included 90 trials of data recorded from 5 groups, each made up of 12-17 individuals.

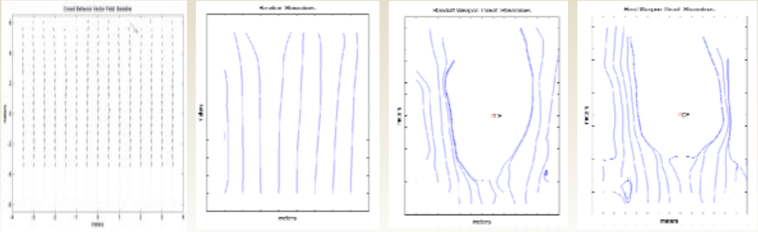
Leading Edge

The average leading edge can be obtained by combining the data from all the trials. This mean performance curve shows how the behavior changed in a general sense. It can be seen that the two non-threat conditions are very similar, not allowing the leading edge quite as far forward and slightly delaying the advance, as well as the delaying the retreat. It can also be seen that in the threat conditions there is a much lower peak of advance and almost no linger time at the closest approach. Under threat, the standoff weapon (green line) seems to keep the leading edge slightly further back than the hand weapon (red line).



Vector Fields

Streamlines were created form the vector fields for better illustration.



CONCLUSION

The methods presented here are critical to investigating the effectiveness of non-lethal weapons in crowd-control force scenarios.

The metrics presented here showed consistency across trials and between groups. The centroid of a group tracked over time showed distinguishable differences between the different conditions of the experiment and is sensitive to the weapon and tactics used. The average leading edge (averaged over all trials) does appear to show the difference in the different conditions of weapon and threat level. Using the average leading edge seems to be a more meaningful metric than leading edge alone due to the variability between individual trials.

The highest dispersions were observed under the no-threat conditions. The dispersion metric may be less meaningful for directly assessing weapon effectiveness (is high or low dispersion more desirable?) but appears a very good measure for characterizing the behavior of the group.

Vector field methods of analyzing the motion show much promise and it is very likely that the behavior of human locomotion can be explained using literal interpretations of Lewinian Field Theory. It was possible to quantify the attractive field of the positive valance goal. It was also possible to create vector fields of the observed locomotion under various combined positive and negative goal conditions. The derived vector field for the negative valance goal conditions alone (by subtracting the underlying positive valance goal behavior from the combined) seems to provide reasonable results, although further testing and analysis is required due to noise in the current data.

Vector field analysis can be used in simulations to predict whether a crowd will stop approach, leave an area, or stay in response to a non-lethal weapon or system. It can also be used to predict whether they will move slowly or stampede. The vector field information could also be used to determine where to place control force personnel, barriers or weapons for effective control of a crowd. The results of the tests provide preliminary evidence that these crowd metrics have face validity, are reliable, and are sensitive to important situational parameters. Therefore, these metrics can be used to assess and compare effectiveness of different non-lethal weapons and systems and their tactics, techniques, and procedures.

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