Kicking and Bleeding: Empirical Testing of an Amputee Trauma Trainer

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ABSTRACT

Battlefield casualties are an unfortunate consequence of military service. Over 50% of all penetrating wounds affect warfighters' limbs, and the most fatal injuries result in exsanguinating hemorrhage (i.e., "bleeding out"). In fact, limb hemorrhage accounts for 10% of all combat deaths in contemporary operations (Champion, Bellamy, Roberts, & Leppaniemi, 2003). However, exsanguination from extremity wounds is often preventable; hence, the Department of Defense continues to emphasize the use of hemostatic procedures.

In the U.S. Army, the Tactical Combat Casualty Care doctrine directs the liberal use of tourniquets (Parsons, 2010), and first responders learn to use the Combat Application Tourniquet® to stop extremity bleeding. Unfortunately, Soldiers typically practice tourniquet application on makeshift training devices, such as a 2x4 wooden plank wrapped with carpet or low-fidelity simulator. Although this helps large numbers of trainees experience tourniquet application, it can have negative training effects. Other training facilities ask trainees to apply tourniquets to one other. This also yields negative training because trainees can only tighten tourniquets to the pain tolerance of their buddies, which may not correspond with the pressure required to stop a real wound.

To address this training gap, the Army has developed the Multiple Amputee Trauma Trainer® (MATT®) simulator, a lifelike lower-limb amputee that includes animatronic movement, bleeding, and physical resistance. Although other tourniquet part-task trainers exist, the MATT® is one of the few that incorporates realistic movement during tourniquet application. To evaluate the training impact of the animatronic movement, we conducted a between-subjects, repeated-measures experiment with 41 Reserve Soldiers. In this paper, we present the results of this study, including the positive correlation between simulator movement and increased trainee speed over time. We also describe the history and contemporary usage of tourniquets, summarize the Army's bleeding intervention procedures, and discuss recommendations for emerging medical simulators.

ABOUT THE AUTHORS

Christine Allen, Ph.D., is an Science and Technology Manager with the ARL HRED STTC. She oversees multiple medical simulation research endeavors. Her expertise includes the areas of casualty extrication, card-based training, and first responder skill assessment. She has transitioned multiple technologies and authored numerous papers and presentations within the medical simulation field. Her previous professional experience includes business owner, program planning and the design, and execution of personal and professional development training. She received her Doctorate in Modeling and Simulation from the University of Central Florida and is a Certified Modeling and Simulation Professional.

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INTRODUCTION

Battlefield casualties are an unfortunate consequence of military service. Over 50% of all penetrating wounds affect warfighters' limbs (Nelson et al., 2008), and the most fatal injuries result in exsanguinating hemorrhage (i.e., "bleeding out"). However, military first responders, or those personnel with combat medical training, can potentially reduce the number of deaths by exsanguination with timely tourniquet application. In this paper, we describe the history and contemporary usage of tourniquets, summarize the Army's bleeding intervention procedures, present the results of an empirical study using a part-task tourniquet simulator, and discuss recommendations for emerging medical simulators.

Why do Tourniquets Matter Now? The Story of 1LT Bernstein

> Even after the bullet cut through his leg and severed his femoral artery, 1st Lt. David R. Bernstein had a chance. The shooting stopped quickly, and a soldier trained in combat medical care was at Bernstein's side almost immediately. Helicopters landed, and minutes later the young platoon leader was surrounded by four surgeons and all the equipment of a modern battlefield trauma center. Bernstein died that night in Iraq, despite getting the best emergency medical care the Army had to offer. But doctors who specialize in combat injuries, and who reviewed details of the case provided by The Sun, question whether the 24-year-old West Point graduate might have lived if the Army had had something else to offer: a $20 nylon-and-plastic tourniquet.
>
> – Robert Little (2005)

In 2003, 1LT David R. Bernstein, USA, was killed in action, despite quick care from military first responders; yet, he might have survived if someone had applied a tourniquet. Unfortunately, 1LT Bernstein's story is not unique. Although physicians have used tourniquets for centuries, their modern availability in both military and civilian settings is often uncertain.

In early 2005, the Senate probed into why tourniquets were not distributed to Soldiers (Little, 2005); this was followed by a Pentagon campaign supporting tourniquet use, and the purchase of more than 172,000 tourniquets for Soldiers and Marines (Bowman, 2005). Today the Tactical Combat Casualty Care (TCCC) doctrine directs liberal tourniquet use within operational doctrine (Parsons, 2010). The year following the massive distribution of tourniquets, SGT Justin Farrar, USA, was assigned to accompany and protect CBS reporter Kimberly Dozier in Bagdad, Iraq. On Memorial Day, 2006, an IED explosion killed most of SGT Farrar's squad and the news team—except for SGT Farrar and Kimberly Dozier. Both had tourniquets applied, and both survived. SGT Farrar attributes the tourniquet, applied by a medic, for saving his life (Beadle, 2010).

History of the Tourniquet

Tourniquets have been used for nearly two millennia; throughout history medics and military personnel have alternatively praised and criticized their use. The ancient Greeks first identified tourniquets as a viable bleeding control device, and the Romans used them, as well. In Europe, both German and French physicians used tourniquets to aid amputations (Moulin, 1998, as cited by Mabry, 2006), and the French first employed them in wartime, during the Siege of Besancon. The French also coined the term "tourniquet" while using the device for military surgery (as cited in LaDran, 1749).

American forces embraced tourniquet use during the Civil War. Due to the large number of casualties, each Soldier began carrying what we consider today to be an improvised tourniquet (i.e., wood and a handkerchief; Mabry, 2006). Modern U.S. military personnel have used tourniquets in every major encounter, including the Vietnam and Korean conflicts, Somali operations, and more recently in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) in Iraq and Afghanistan, respectively. Figure 1 shows the contemporary U.S. Combat Application Tourniquet® (CAT), the official tourniquet of the U.S. Army.

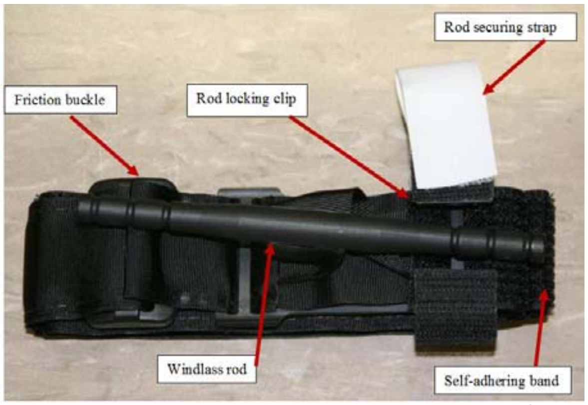

Figure 1. Combat Application Tourniquet®

Modern Tourniquet Effectiveness

Until recently, few clinical studies had investigated the "effectiveness of tourniquets on hemorrhage control and casualty outcome" (Beekley et al., 2008, p. S28). However, in the last few years, leading physicians in actual military theaters have begun publishing more studies to answer questions of both tourniquet effectiveness and limb outcomes by tracking injured patients (see Beekley et al., 2007, 2008; Kragh et al., 2008, Kragh et al., 2009a; Kragh, 2010). In modern-era conflicts all around the world, lower limb extremity wounds occur frequently. For the U.S. military, the frequency of these injuries may be exacerbated by the personal protective equipment worn by Soldiers. U.S. personnel wear body armor that protects their chest and head regions, which severe battlefield wounds in those areas (Carey, 1987) but may increase the number of extremity injuries, as seen in conflicts such as Panama, Somalia, Iraq, and Afghanistan (Bohman et al., 2005).

At the beginning of the Iraq and Afghanistan conflicts, for instance, extremity injuries accounted for over 50% of the injuries, with 70% of tourniquet application occurring in the lower body limb region (Nelson et al., 2008). During OIF, tourniquets were "liberally used on all patients involved in close range IED explosions with significant lower extremity fractures with no active hemorrhage identified at the time of presentation to the Shock Trauma Platoon (STP)" (Nelson et al., 2008, p. 212). During that timeframe, 165 patients with traumatic amputations and prehospital tourniquet application showed improved hemorrhage control; especially with those more severely injured (Beekley et al., 2008). Surgeons noted the benefits of the pre-hospital tourniquet to control hemorrhage at the point of injury after assessing casualties arriving to theater hospitals (Beekley, Starnes & Sebesta, 2007).

ARMY TOURNIQUET TRAINING

In the U.S. Army, first responders, including Combat Medics and Combat Lifesavers (CLS), provide the immediate medical treatment needed to sustain Soldiers in combat, helping to close the gap in treatment time between the battlefield and the Battalion Aid Station (BAS). To train their tourniquet skills, Army first responders traditionally practice tourniquet application on makeshift training devices or antiquated part-task trainers. Although this helps large numbers of students experience tourniquet application, it can create negative training effects since these devices do not effectively simulate limb soft tissue. Alternatively, some training facilities ask trainees to apply tourniquets to each other. Although higher fidelity than other makeshift training devices, such "buddy training" still yields negative outcomes because trainees can only tighten their tourniquets to the pain tolerance of their "buddies," which may not accurately reflect the torque needed to stop a dynamic wound.

More recently, some Army medical training facilities have acquired full-body mannequins that allow students to perform multiple interventions, including tourniquet training. These simulators, such as METIman, SimMan® 3G, and S3101 HAL® (METI, n.d.; Laerdal, n.d.; Gaumards, n.d.), allow trainees to treat the entire body of the simulated casualty, performing bleeding control and airway management procedures, while being tracked by an automated performance assessment system. These devices offer higher fidelity but are often expensive and may not include amputations or other limb deformations indicative of battlefield lower-extremity trauma.

Others have explored the use of tourniquet part-task trainers, devices that focus on singular medical body systems and procedures, to practice bleeding control. A recent within-subjects study using medical students, conducted by the Army Research Laboratory (ARL) and presented at I/ITSEC 2011, evaluated three upper extremity hemorrhage part-task trainers (Hackett, Norfleet, & Petttitt, 2011). The three devices included Simulaids' arm tourniquet trainer attached to an upper torso, Metter's arm tourniquet trainer attached to a hinge, and HapMed's stand-alone arm tourniquet trainer. Participants rated the Metter trainer most favorably, followed by the Simulaids. Participants rated realism ("realistic pulse, pulse location, skin, and perceived realism") highest for the Metter's system, with the Simulaids following second. Other considerations, including cost, throughput, time-savings, effectiveness, and safety also factored into the analysis. In the end, the authors expressed the need for more realistic tourniquet trainers that reduce the gap between training and reality.

Tourniquet Training with Movement

Regardless of their realism and quality, typical full-body simulators and part-task trainers lack movement. This means that even state-of-the-art devices fail to represent this common—and particularly challenging—aspect of tourniquet application. To address this need, ARL invested in the development of the Multiple Amputee Trauma Trainer® (MATT®), a lower-body bilateral amputation tourniquet trainer that incorporates movement via animatronics technology (Sotomayor & Parsons, 2011). DNovus (now KGForce) developed the initial MATT® system with assistance from Jamie Hyneman of M5 Industries, the special effects firm behind the television series "MythBusters." The developers drew upon their special effects experience from Hollywood in order to increase the system's touch, feel, and interaction—and, of course, incorporate animatronic movement. Figure 2 shows the MATT® along with Jamie Hyneman and ARL HRED STTC's Mr. Bill Pike and Dr. Teresita Sotomayor.

Figure 2: MATT® Simulator 2009

The second-generation MATT®, called the *Advanced* MATT®, includes a lower-torso bilateral traumatic amputation (which bleeds from both limbs), movement via animatronics, pressure sensors that detect the force of applied tourniquets, and automated performance measurement capabilities. When trainees apply a tourniquet to the Advanced MATT®, bleeding ceases only if they have placed the tourniquet correctly and tightened it sufficiently. Developers hypothesized that these enhancements could further increase the trainer's realism and create more effective training experiences. To evaluate these claims, we conducted an empirical evaluation of the Advanced MATT®, comparing its utility with and without the animatronic movement.

MATT® TRAINING EFFECTIVENESS EVALUATION

Method

Participants. Forty-one (*N* = 41; 32 males, 9 females) enlisted military first responders and medical personnel from the U.S. Army Reserves participated in this study as part of their regular refresher training. Participants ranged from 20 to 52 years old and held ranks between private and major. Their experience (between 2–30 years) and educational preparation (from high school to post-graduate) also varied widely. Twenty-four of the participants held medical military operational specialties, and about half of the participants had been previously deployed. All participants had received training on tourniquet application previously, and six had applied a tourniquet in combat.

Table 1: Participant Group Distribution

Groups	Trial and Movement			*N* per Group
	Practice	Immersive Scenario 1	Immersive Scenario 2	
Control, Group 1	NM	NM	M	13
Control, Group 2	NM	M	NM	8
Experimental, Group 3	M	NM	M	10
Experimental, Group 4	M	M	NM	10

NM = No movement, M = Movement

The participants were evenly distributed among four groups, and random assignment ensured that the four groups were homogeneous for all meaningful variables (as evaluated via an ANOVA). Each group completed three trials with the Advanced MATT®, either with or without its animatronic movement. Table 1 shows the distribution of participants per group and which trials each group experienced the moving MATT®.

Experimental Design. This study used a 2-X-2 crossover, repeated-measures, mixed-model design. In other words, all participants completed multiple trials, and some of their trials included the animatronic movement. This allowed all trainees to complete the hypothesized better training (i.e., with movement), while still enabling controlled experimental comparisons between groups. Specifically, all participants completed the following activities:

1. Pre-training lecture. Before hands-on training began, all participants listened to a presentation on tourniquet application. The experimenters developed this material based upon Army CLS training, which is the standard introductory training material used at Army Medical Simulation Training Centers. During the lecture, the experimenters demonstrated tourniquet application and reviewed the appropriate steps to stop lower extremity bleeding.

2. Initial data collection. While in the classroom, the experimenters informed participants of the study, received informed consents, and collected basic demographic information.

3. Practice session. All participants interacted with the Advanced MATT® three times. First, participants practiced applying tourniquets to the MATT® in a calm, classroom-like setting. The experimental groups applied their practice tourniquets to the moving MATT® while the control groups practiced on the MATT® without movement.

4. Immersive scenario, trial 1. Following their practice session, trainees completed two immersive scenarios, with either the moving or stationary MATT®, (see Table 1). Before entering the immersive scenario, all participants were briefed on a fictitious situation involving a casualty event. They were told that a unit on a convoy mission had encountered an IED. Fire had been suppressed, and now they must perform Care Under Fire (CUF) to treat the lower-limb bleeding of an injured medic. Each scenario began once the participant entered the door.

Figure 3: Immersive Scenario Tourniquet Application

These scenarios included environmental effects, such as a dark room, battle sounds, strobe light, and fog. The effects were generated approximately three feet from the left side of the Advanced MATT, which was placed on the floor at exactly 173 inches from the door (see Figure 3). To reduce uniform staining, simulated blood mix was not used (per instructor request); instead, experimenters filled the MATT® with water, which simulated blood. All trials used this room set-up, and special care was taken to ensure that the scenarios were identical for all participants.

Each experimental trial was completed by a single participant at a time. Trials lasted an average of 3–7 minutes, beginning when a participant entered the room and ending once a tourniquet was successfully applied to each leg. Left and right (combined) total tourniquet application time was limited to five minutes. After five minutes had been reached, participants were thanked and asked to leave, regardless of whether or not they had successfully completed tourniquet application. Successful completion was defined as total cessation of blood flow (i.e., no remaining trickle of blood flow). Five minutes was chosen as the maximum time limit because exsanguination during combat occurs within 5 to 10 minutes (Champion et al., 2003) and may be as little as 2 minutes in severe cases (Wenke, Walters, Greydanus, Pusateri, & Convertino, 2005).

5. Immersive scenario, trial 2. Trainees completed two identical immersive scenarios. Depending upon the group to which they were assigned, these scenarios included movement or no movement from the MATT®, (see Table 1). In other words, trials 1 and 2 were identical, except that each participant experienced the animatronics in one of the scenarios and no-animatronics in the other.

Measures. This study explored the role of amputee movement as it relates to performance and perceived preparedness. These factors were evaluated based upon measures of reaction and completion time. Table 2 summarizes these variables, and the hypotheses associated with them are described below.

Table 2: Dependent Variables

Name	Description
Reaction time	Start: Crosses door threshold End: Lays hands on MATT®
Left tourniquet time	Left leg tourniquet time
Right tourniquet time	Right leg tourniquet time
Left /right total time	Left + right leg times
Total exercise time	Reaction + application times

1. Reaction time (time to begin tourniquet application). Anecdotal reports reveal that new first responders often struggle with rapid decision-making when confronted by horrific battlefield injuries. In contrast, more experienced first responders have improved reaction time and can make decisions more rapidly. This experience, and the resulting performance benefits, may be gained by using simulation. For instance, Vincent et al. (2009) found that medical students using high-fidelity mannequins in a simulated mass casualty event improved in speed and self-efficacy following the training. Additionally, we hypothesized that greater realism (such as movement) might better inoculate trainees to some negative effects of operational stressors and thereby further improve their operational reaction times.

> H1 – In the immersive scenario, the experimental groups (i.e., those trained on a moving simulator) will have a faster reaction time as compared to those participants who did not receive training on the moving Advanced MATT® simulator.

2. Tourniquet application time (time to complete application). Exsanguination during combat occurs over a "usual" time span of 5 to 10 minutes (Champion et al., 2003), and tourniquets applied faster may help to save lives. The time dependent nature of tourniquet application leads to the next hypothesis:

> H2 – In the immersive scenario, the experimental groups (i.e., those trained on a moving simulator) will have a faster tourniquet application time when presented with movement.

Data Collection Logistics. Two trained experimenters collected the reaction and application times via stop-watches, and compared their results to increase measurement accuracy. Prior to the experiment, a pilot test with six participants was conducted to help the two experimenters become accustomed to recording the reaction and tourniquet application times. *Reaction time* began when a participant crossed the door threshold and ended when he/she first touched the Advanced MATT®. *Tourniquet application time* (left leg and right leg) began when a participant placed his/her hands on the Advanced MATT®, and ended when bleeding cessation occurred for a given limb. *Left/right total time* comprises the total time required to apply tourniquets to both legs, which is simply a combination of each individual leg, and *total exercise time* simply reflects the reaction time and left/right total time, combined.

RESULTS

General Training Effect

Before evaluating the hypotheses, the impact of training, in general and regardless of condition, was assessed. In other words, an analysis was conducted to determine whether participants' performance improved over the three trials. A repeated-measure ANOVA was conducted for the three trials (practice, scenario one, and scenario two), where the independent variable was the trial number and the dependent variables included the five time-based measures listed in Table 2 (i.e., reaction time, left tourniquet time, right tourniquet time, left /right total time, and total exercise time). The analysis revealed a significant effect for trial on reaction time, $F(1, 40) = 6.73$, $p < .01$, left leg tourniquet application time, $F(1,40) = 7.42$, $p = .01$, left and right leg total tourniquet time, $F(1, 40) = 4.18$, $p = .02$, and total exercise time, $F(1, 40) = 4.05$, $p = .03$. This indicates that the experimental intervention (i.e., tourniquet practice on the Advanced MATT®) improved participants' performance regardless of condition. Table 3 displays the mean times in seconds seen across the practice to scenarios.

Except for reaction time, the general trend was an increase in time (worse performance) from practice-training to scenario one, followed by a decrease in time (better performance) in scenario two. This trend was expected as the practice-training contained lights on with no stressors and the immersive scenarios contained darkness and battlefield effects (smoke, strobe light, and battle sounds). As seen in Table 3, a significant training effect did ultimately occur, after the second scenario, as trainees improved across the trials.

Table 3: General Training Effect

Dependent Variables	*N*	Practice		Scenario 1		Scenario 2		F	*p*	Partial Eta^2 (Effect Size)
		Mean	SD	Mean	SD	Mean	SD			
Overall reaction time (seconds)	41	5.68	3.01	4.41	1.58	4.00	1.15	6.73	**.003**	.257
Left time (seconds)	41	59.67	30.79	100.22	60.56	74.78	46.79	7.42	**.002**	.276
Right time (seconds)	41	85.80	72.35	97.07	60.09	79.98	54.11	1.26	.295	.061
Left /right total time (seconds)	41	147.90	86.62	199.51	95.49	164.63	80.72	4.18	**.023**	.177
Total exercise time (seconds)	41	153.56	86.50	203.88	95.91	168.63	80.78	4.05	**.025**	.172

Hypothesis 1: Immersive Scenario Reaction Time

For this hypothesis, three analyses were conducted. The first analysis compared the reaction times in immersive scenario one for Group 1 versus Group 3 (i.e., the two cohorts that experienced the static Advanced MATT® during immersive scenario one), and it compared Group 2 versus Group 4 (i.e., the two cohorts that experienced the moving Advanced MATT® in the first immersive scenario), as referenced in Table 1. The second analysis compared reaction times in immersive scenario two for Groups 1 versus 3 (experienced movement) and Groups 2 versus 4 (no movement). Finally, during the third analysis, the reaction time scores for the two control groups were pooled together across both immersive scenarios; similarly, reaction time scores were pooled for the experimental groups across the two immersive scenario trials. Then the consolidated reaction time scores for the control cohorts (Groups 1 and 2 across both scenarios) were compared to the consolidated reaction time scores for the experimental cohorts (Groups 3 and 4 across both scenarios). By doing this, the downstream effects of the practice trial (i.e., with or without the animatronics in the initial practice) were evaluated.

In scenario one, experimental Group 3 (Practice=M, Scenario_1=NM) had better reaction times (M = 4.10, SD = 1.10) than did control Group 1 (NM, NM) (M = 4.85, SD = 1.13), $F(1,21)$ = 1.13, p = .300. Experimental Group 4 (M, M) had better reaction times (M = 4.00, SD = 1.33) than did control Group 2 (NM, M) (M = 4.63, SD = 1.69), $F(1,16)$ = .77, p = .39. Although not statistically significant, the better (faster) reaction times demonstrated by the experimental groups (3 and 4) may indicate improved performance based upon the practice trial with movement and overall impact of movement.

In scenario two, the reaction time of Group 3 (Practice=M, Scenario_1=NM, Scenario_2=M) was better (M = 3.75, SD = .99) than Group 1 (NM, NM, M) (M = 4.25, SD = 1.42), $F(1,21)$ = 1.13, p = .350. Group 4 (M, M, NM) had better reaction times (M = 3.77, SD = .84) than did Group 2 (NM, M, NM) (M = 4.10, SD =1.10), $F(1,16)$ = .80, p = .384. Again, although not significant, the better (faster) reaction times demonstrated by the experimental groups (3 and 4) may again indicate improved performance based upon the practice trial with movement.

The third analysis compared the two experimental groups' combined reaction time scores to the two control groups' reaction times in the two immersive scenarios. The experimental groups (3 and 4) demonstrated significantly better reaction times (M = 3.90, SD = 1.05) than did the control groups (1 and 2), (M = 4.50, SD = 1.61), $F(1,80)$ = 3.90, one tailed p = .026 (see Table 4 and Figure 4). These results suggest that the experimental groups (who trained with a moving Advanced MATT® during the practice trial) performed better on the immersive scenarios, overall, than did their control groups counterparts.

Table 4: General Training Effect

Reaction Type	Group Type	*N*	Mean	SD	*F*	One-tailed *p*	Partial Eta^2 (Effect Size)
Reaction Immersive Scenario	Control (Groups 1 and 2) No Movement	21	4.50	1.61	3.90	**.026**	.05
	Experimental (Groups 3 and 4) with Movement	20	3.90	1.05			

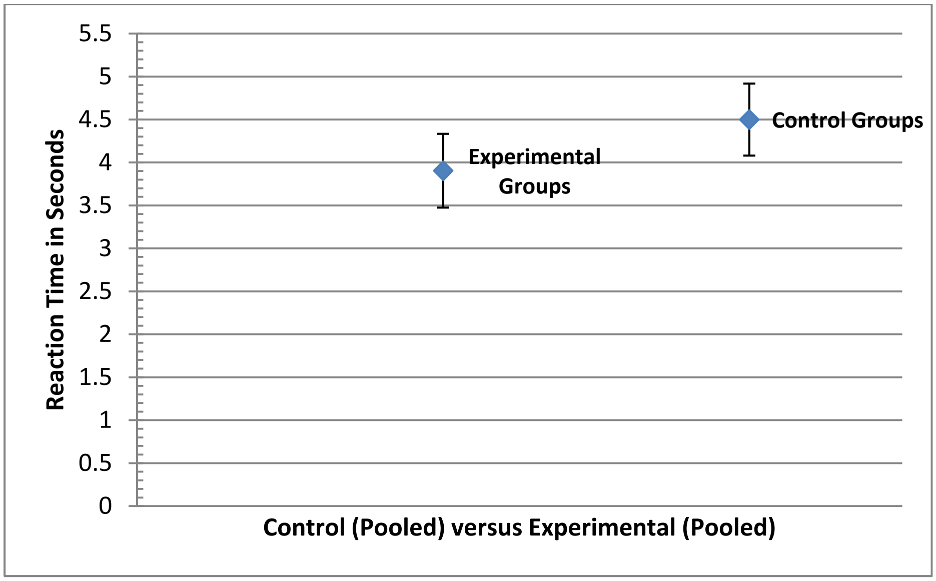

Figure 4: Experimental Versus Control Group Immersive Scenarios Reaction Time (Lower is Better)

Hypothesis 2: Immersive Scenario Tourniquet Application Time

For this hypothesis, three analyses were conducted. The first analysis compared the tourniquet application times in immersive scenario one for Group 1 versus Group 3 (i.e., the two cohorts that experienced the static Advanced MATT® during immersive scenario one), and it compared Group 2 versus Group 4 (i.e., the two cohorts that experienced the moving Advanced MATT® in the first immersive scenario), as referenced in Table 1. The second analysis compared tourniquet application times in immersive scenario two for Groups 1 versus 3 (now experienced movement during the second immersive scenario) and Groups 2 versus 4 (now experienced no movement during the second immersive scenario). Finally, in third analysis, the tourniquet application time scores for the two control groups were pooled together across both immersive scenarios; similarly, tourniquet application time scores were pooled for the experimental groups across the two immersive scenario trials. Then the consolidated tourniquet application time scores for the control cohorts (Groups 1 and 2 across both scenarios) were compared to the consolidated tourniquet application time scores for the experimental cohorts (Groups 3 and 4 across both scenarios). By doing this comparison, the downstream effects of the practice trial (i.e., with or without the animatronics in the practice trial practice) were evaluated.

In scenario one, experimental Group 3 (Practice=M, $Scenario_1$=NM) had better reaction times for left and right leg total tourniquet time (M = 203.50, SD = 86.78) than did control Group 1 (NM, NM) (M = 208.31, SD = 107.06), $F(1,16) = .01$, $p = .909$. Experimental Group 4 (M, M) had better reaction for the left and right leg total tourniquet time (M = 190.80, SD = 98.60) than did control Group 2 (NM, M) (M = 191.12, SD = 99.61), $F(1,16) = 3.21$, one tailed $p = .044$. These significant results may be reflective of the influence of movement during training.

In scenario two, for the left and right leg total tourniquet application time, Group 3 (M, NM, M) reported better tourniquet application time (M = 147.80, SD = 74.94) than did Group 1 (NM, NM, M) (M = 207.77, SD = 82.88, $F(1,21) = .00$, $p = .995$. Note: the slowest overall mean tourniquet application time was seen from Group 1 who received movement for the first time, during trial three. Group 4 (M, M, NM) also reported better tourniquet application time (M = 133.87, SD = 69.17) than did Group 2 (NM, M, NM) (M = 150.00, SD = 79.88), $F(1,16) = .20$, $p = .658$. Although not significant, the better (faster) left and right leg total tourniquet application times demonstrated by the experimental groups (3 and 4) may indicate an effect of experiencing movement in the practice trial.

For the third analysis, the combined control groups' left and right leg total tourniquet application scores were pooled across the two immersive scenarios and compared to the two experimental groups' left and right leg total tourniquet application scores, which were also pooled across the two immersive scenarios. The experimental Groups (3 and 4) demonstrated better left and right leg total tourniquet application times, (M = 173.20, SD = 85.84) than did the control groups (1 and 2), (M = 190.60, SD = 93.26), $F(1,80) = .79$, $p = .37$, although, the results are not statistically significant.

DISCUSSION

Controlling bleeding using a tourniquet is an important skill for military first responders. Standard, static medical simulation tourniquet trainers provide training opportunities to increase skill level; however, more effective tourniquet simulators may be available. The Advanced MATT® lower limb simulator is a dynamic tourniquet trainer incorporating limb movement, and this study empirically investigated whether its animatronics meaningfully affected tourniquet training. During this experiment, participants completed three trials with the Advanced MATT®. For their practice training, trainees applied a tourniquet to the Advanced MATT®. Control group participants interacted with static simulator, while the experimental groups experienced the simulator with the animatronic movement. Following this trial, two immersive scenarios with battlefield effects were conducted. Each of the four groups had the opportunity to experience the Advanced MATT® with animatronics either during immersive scenario one or two. The participants were evaluated based upon their reaction and tourniquet application completion times; we hypothesized that training with animatronic movement would eventually decrease reaction and tourniquet application times (i.e. faster times), following initially slower times in practice trial results.

First, an analysis was conducted to evaluate the overall utility of the Advanced MATT® simulator to support tourniquet (i.e., bleeding control) training. There were significant positive training effects found between the three training trials (practice, scenario one, and scenario two), specifically for reaction time, left tourniquet time, left and right leg total tourniquet time, and total exercise time. These results imply that the Advanced MATT® simulator is effective as a training aid.

The second analysis examined the impact of movement-based tourniquet application practice on reaction and tourniquet application times during practice, immersive scenario one, and immersive scenario two. Overall general observations include: all groups, regardless of the impact of movement improved reaction time from immersive scenario one to two. This improvement may be attributed to the repetition of the same scenario either with or without movement. However, the experimental groups (practiced with movement) outperformed the reaction times of the control groups. Finally, all tourniquet application times were slower with the addition of animatronic movement versus the static Advanced MATT®. In this case, the experimental groups also outperformed the control groups in tourniquet application time. This further reveals the impact of movement within this experiment, translated to enhanced reaction and tourniquet application times within an immersive trial.

To further illustrate the effect of the Advanced MATT® movement capabilities, participant reaction questionnaires noted comments related to this experiment such as, "more realistic than what I have trained before, the movement of the simulated amputee made training more realistic, and the movement of the MATT® provided a real-life experience." It is suggested by the improved reaction and tourniquet application times of the experimental groups (i.e., those who received animatronic movement during training) that the movement capabilities of the Advanced MATT® had a positive impact on training. Furthermore, as hypothesized, the reaction and tourniquet application times were reduced (slower times) during the practice session, followed by faster times. This seemingly small detail is important as this same initial reduction in initial reaction and tourniquet application time seen in training could likely translate to the battlefield environment. Furthermore, seconds count within the immersive battlefield environment and improvements in reaction and tourniquet applications times may translate into the difference between life and death.

Overall differences were found in the tourniquet application times between the left (above knee amputation) and right (below knee amputation with bones and shrapnel exposed) legs, as seen in Table 3 and Figure 3. One possibility is that the severity of the right leg (bones exposed) would either lead to faster (looks worse) or slower (this is going to take longer or is intimidating) tourniquet application. Informal participant comments and observations during the practice and immersive scenarios suggest that participants felt visually overwhelmed and more intimidated by the right leg. Participants also verbalized comments during the trials, such as "I keep having a hard time with this leg," which explains why they applied tourniquets to the left leg at a different rate than the right leg. These types of comments and actions were heard throughout the three trials.

The differences in the left and right leg are relevant for military and civilian trauma medicine. On the "battlefield," both home and abroad, there are many different types of amputations, two of which were seen in Figure 3. Individual subjective reactions differ for each type of limb amputation. Differences include the location above or below the joint, graphic flesh and tissue damage, bone and shrapnel fragmentation, not to mention the odors associated with injury. If the results reported in this study are indeed a trend in tourniquet application, it is important to examine the aforementioned differences further. Finally, these observations and documented reaction and tourniquet application times can translate into the schoolhouse or training facilities, better informing the practice of applying a tourniquet or pressure bandage to many different types of amputations, potentially decreasing treatment time, and providing stress inoculation.

SUMMARY

Although this research focuses on tourniquet application in the military realm, tourniquets and movement-based simulators can be especially helpful during civilian training for events such as the Columbine shootings, World Trade Center, Oklahoma City Federal Center bombing, other urban-style conflicts, as well as in rural, farm-based injuries where there is great distance to transport to hospitals (Walters et al., 2005). More recent incidents such as the Colorado Movie shootings and Boston Marathon bombings support the importance of tourniquet application and exsanguination training in the civilian realm. In these mass casualty events, like during "care under fire," tourniquet application may be one of the only interventions able to stop bleeding on the "civilian battlefield." Rescue personnel may not be able to apply direct pressure to the wounds, while the injured may move in pain, grab at their caregivers, or fight care. Adding movement to medical simulators for first responder training may increase self-efficacy and engender improved performance on the battlefield (i.e., military or civilian).

The return on investment of increased performance and potential self-efficacy, specifically, may provide a downstream benefit. Since, as this study demonstrated, there is no additional cost-impact as compared to static simulators (either financially or to the effectiveness or efficiency of training), movement-based simulation may provide more benefits such as improved operational times (faster reaction and left leg tourniquet application) as seen with the experimental groups trained with movement. Reaction and tourniquet application times improved the most for the experimental group, receiving animatronic movement during training. This improvement in treatment time using movement-based training could potential save lives. Finally, it is interesting to note that, overall, movement did not appear to have a negative impact. It did not slow reaction considerably or tourniquet application times, even on its first introduction to participants. At best there may be small performance improvements as a result of movement-based tourniquet training, as indicated by the significant overall training results, and at worst there is little-to-no added costs (as compared to static tourniquet simulators) and at least equivalent training outcomes as a result of training with a moving tourniquet simulator.

FUTURE RESEARCH

Since the development of the Advanced MATT®, the STTC has dedicated research and funding for an additional lower body prototype simulating a deep groin, non-compressible wound. Such a wound requires packing or a hemostatic agent (i.e., an agent that ceases bleeding). The trainer incorporates leg movement and double amputation. Additionally, an upper body prototype was developed incorporating animatronic movement and an axillary wound, which also required packing or hemostatic agent, and this upper body trainer includes facial movements (eye and mouth squinting and tensing) indicative of pain. These developments reflect the belief that movement plays an important role in mimicking a severely injured conscious casualty in simulation, and future research will continue to explore the impact that these features have on the outcome of military medical training.

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