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Research Article

Kinematic Analysis of Naive Shooters in Common Law Enforcement Encounters

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ABSTRACT

Purpose: To kinematically analyze naive shooters during eight common shooting motions frequently encountered in previous assaults on Law Enforcement Officers (LEOs).

Methods: A total of 20 naïve male shooters (age=27 y ± 4 y; body weight=82 kg ± 14 kg; height=181 cm ± 6 cm) completed 3 trials of each stationary and dynamic movement wearing body sensor technology (ADPM Technologies, Portland, OR). Time to complete each of the eight motions was recorded in seconds. A laser point training pistol was fired at a paper silhouette shaped like a LEO. Kinematic motions were examined by descriptive analysis, variability within the trials assessed by a reliability analysis, and between group differences across each of the motion type categories determined by repeated measures ANOVAs.

Results: Times (s) for each shooting scenario were as follows: Shooting seated and facing toward the driver's -side window (0.50 ± 0.25); shooting seated and facing toward the passenger's side window (0.64 ± 0.29); waistband draw facing LEO (1.13 ± 0.21); shooting positioned 90° to target then fleeing (0.42 ± 0.12); shooting facing the target then turning 180° and fleeing (0.38 ± 0.11); with back facing target, rotating the torso, shooting, then fleeing (0.49 ± 0.12); fleeing, then shooting over the opposite shoulder (0.51 ± 0.14) and; fleeing then shooting under the opposite shoulder (0.64 ± 0.22). Standard error of measurements for the 3 trials ranged 0.04 s to 0.12 s. Time to back and head rotation in fleeing conditions ranged 0.41 s to 0.43 s following weapon discharge.

Conclusion: This study demonstrates rapid execution and consistency during eight common LEO encounters suggesting a short decision-making timeframe. Future research should examine the training and legal implications of these findings.

Keywords: Kinematic analysis; Law enforcement; Shooting performance; Variability; Naive shooters

INTRODUCTION

The sudden spotlight on Law Enforcement Officers (LEOs) using lethal force has been brought to the forefront of the public by the media. Bozeman and colleagues published an epidemiological study involving >1 million calls for service and reported the actual use of force (UoF) incidences from three mid-sized police departments, totaling 1,916 sworn officers [1]. The incident rates for UoF were observed at 0.78% in criminal arrests (1 in 128 arrests) and even lower in general service calls at 0.086% (or 1 in 1167 calls). Incidences involving the use of firearms were extremely rare at 0.4%. These data provide compelling evidence to the contrary of the prevalence suggested by the popular press and media. In general, >99% of the time, LEOs do not rely on UoF to mediate problems.

Although rare, LEOs are exposed to violence which can lead to injury for them and/or civilians [2]. On the national level, an average 1000 civilians are killed annually from LEO-involved shootings, and in 2018, 55 LEOs died from injuries in the line of duty [3,4]. In 2019, 35 officers died [5]. The majority of these deaths were caused by handguns. LEOs are often required to make split-second decisions when utilizing force with a firearm to protect civilians and themselves from assailants who are threatening the lives of these individuals [6]. When officers are faced with a threat from an assailant, it takes approximately 0.46 s to 0.70 s to

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recognize and process the threat and to begin a physical response, and up to 1.94 s to un-holster their firearm and return fire [7-11]. The movement time from initiation of the threat to containing the threat is <2 s, highlighting the need for the LEOs to contain and control, as much as they can, spontaneously arising or escalating lethal situations.

To date, most studies have examined the LEOs performance in tactical situations, however, knowledge on an assailant's movement during such encounters is lacking. Such information on assailants carrying out shootings on LEOs when examined both temporally and kinematically may influence LEO training, forensic, and legal implications for UoF situations. Therefore, the purpose of the present study was to describe the kinematic characteristics of naïve male shooters during eight different stationary and dynamic shooting scenarios frequently encountered by the LEOs in tactical situations. We also evaluated the variability of each of these actions in naïve male shooters to highlight the range of movement performance noted in such encounters.

METHODOLOGY

Experimental overview

We examined eight different scenarios of LEO-involved shootings, which have been utilized in previous research [12]. Stationary scenarios included: 1) an assailant seated in the driver's seat with a gun in their hand and simulating shooting out of a driver's side window at a target resembling a police officer; 2) an assailant, seated in the driver's seat, with a gun in their hand and shooting out of the passenger's side window at a target resembling a police officer; and 3) an assailant facing a target resembling an LEO and drawing a pistol from their waistband, pointing, and shooting. Shooting then fleeing scenarios included: 4) 90° Turn: an assailant with the weapon held in their hand and concealed on their posterior thigh in the so-called "bootleg" position. The assailant was positioned at a 90° angle to the target with their dominant side facing the target and visually focused on the face of the officer. Then the weapon was rapidly pointed and fired, followed by a 90° angle turn and flight away from the target; 5) 180° Turn: an assailant facing the target with the weapon held in their hand in the bootleg position, rapidly points and fires at the target followed by a 180° turn and flight away from the target; and 6) a Strong Side Turn: an assailant has their back facing the target with the weapon held in their hand and concealed on the anterior thigh, turns rapidly to shoot and then flee. Lastly, fleeing and shooting scenarios of LEO-involved shootings included: 7) an assailant while fleeing moves the gun cross body, and under the opposite arm, points it back toward the officer and shoots, and 8) an assailant fleeing the officer and pointing the gun and shooting over the opposite shoulder. Refer to the Appendix Figure for visual representation of each of these shooting scenarios starting positions, gun fire positions, and back turn positions. For this study, 20 naïve male shooters were asked to engage in these eight scenarios and their kinematic performance was recorded.

Subjects

Study participants were recruited from the local community using non-probability methods of sampling, fliers, and email communications. A total of 20, right-hand-dominant males (age=26.5 y ± 3.9 y; body weight=82 kg ± 14 kg; height=181 cm ± 6 cm) volunteered to participate in the study. A sample size of 20 subjects was selected based on previous research, which had determined the time taken to respond during common shooting motions faced by LEOs. Subjects were included if they were males, between the ages of 18-37 years, and reported no previous firearms training. Subjects were excluded if they reported any current injuries that would limit their participation in the study. These sample demographics were selected specifically based on commonly reported characteristics of individuals frequently involved in police shootings [12]. All subjects read and signed an informed consent document. The study was approved by the Rocky Mountain University of Health Professions Institutional Review Board (Protocol #180536-02; February 19, 2019), and certified that the study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Procedures

Prior to engaging in any of the eight specific motions, subjects viewed a narrated slow-motion video demonstration of that motion. This was followed by a video demonstration played at full speed. They were then given time to practice each scenario and were instructed to shoot with a simulation pistol (SIRT Model 110; Ferndale, Washington) which has the same weight and feel as a Glock 17/22; however, the trigger pull corresponded with a laser light pointer emitting from the barrel. The subjects (assailants) shot toward a stationary target, which was a poster board police officer silhouette mounted on a tripod easel. Subjects typically engaged in two to three practice trials before they indicated they were ready to ensure a basic understanding of each motion (i.e., shoot then run, run then shoot), at which point the researchers collected three trials of recorded performances for the experiment. In the case of equipment malfunction, or subject error, an individual trial was re-done. Previous research supports the use of 2-3 practice trials to limit the practice and motor learning effects while assessing a task [13,14].

The distance of the subject from the target was standardized to provide the same environment for each subject. In the driver's-side scenario (seated), the target distance was three ft. (91 cm), the target distance in the passenger's-side scenario (seated) was six ft. (182 cm). These distances approximate the distance of an LEO standing in front of each window relative to a seated driver. The distance of the subject in both the standing and fleeing scenarios was three ft. (91 cm). The distances were identified with tape placed on the ground. The silhouette was provided to give subjects something at which to aim and shoot; however, target accuracy was not collected in this study.

In each of the scenarios, the "assailants" dictated the initiation of the motion (i.e., the participants were not asked to react, draw, and fire on command or in reaction to a stimulus). Therefore, there is no delay in reaction time for these actions. This study simply examined the kinematic performance of eight common threats of lethal force facing LEOs. Thus, these times may accurately reflect what a LEO could face if presented with these situations typically initiated by an assailant.

Kinematic performance or time taken to perform the shooting motion

Time to complete each of the eight motions was calculated by subtracting the time of termination of each motion from the time of initiation of each motion, as displayed in the Appendix figure for each motion. Motion initiation and termination time stamps were determined by the joint angle time plots as described in Table 1. In addition, the initiation and termination time stamps were cross-referenced for accuracy with the video recordings of each trial.

Table 1: Time points for initiation and termination of shooting and back turn for fleeing scenarios.

Scenario	Initiation of movement	Termination of shooting	Back presented to the LEO
Stationary shooting			
Shooting at officer out of the driver's-side window	Initiation of shoulder flexion	Peak elbow extension/ shoulder adduction	N/A
Shooting at officer out of the passenger's-side window	Initiation of shoulder abduction	Peak elbow extension/ shoulder abduction	N/A
Drawing from waistband and shooting at officer	Initiation of elbow flexion	Peak elbow extension	N/A
Shooting and fleeing			
90° Turn	Initiation of shoulder abduction	Peak shoulder adduction	Peak right hip extension following trigger pull
180° Turn	Initiation of shoulder flexion or abduction	Elbow extension	Peak right hip extension following trigger pull
Strong side turn	Initiation of shoulder extension	Peak shoulder external rotation	Peak right hip extension following trigger pull
Fleeing and shooting			
Back to officer, cross body shot under opposite arm pit, continue running away from officer	Initiation of shoulder internal rotation	Peak shoulder internal rotation	Peak right hip extension following trigger pull
Back to officer, cross body shot over opposite arm, continue running away from officer	Initiation of shoulder internal rotation	Peak shoulder internal rotation	Peak right hip extension following trigger pull

Statistical analysis

The kinematic performance for each motion was first determined by conducting a descriptive statistical analysis and results were reported in mean ± Standard Deviation (SD). To determine the variability within the 3 trials for each motion, a series of Intraclass Correlation Coefficients (ICC α), Typical Error (TE) (s), and coefficient of variation (CV% variability) were calculated [15]. This analysis was conducted to examine the consistency between trials from each subject and for the sample as a whole. Between-trial variance can typically reflect both measurement error and variability of the subject's movement between-trials. Furthermore, motion category-based differences in time taken to perform each of the 3 stationary motions were determined by one-way ANOVAs with repeated measures and post-hoc Tukey comparisons. This analysis was repeated for determining differences in the three shooting then fleeing motions. Lastly, a paired t-test was used to evaluate the differences between the two fleeing and shooting motions. Effect size differences for significantly different shooting times are reported using Cohen's d.

RESULTS

Kinematic performance of common shooting motions

The time taken to perform each of the stationary, shooting then fleeing, and fleeing then shooting motions is described in Table 2. The fastest times reported for each motion were as followed: driver side (0.28 s), passenger's side (0.33 s), waistband (0.81 s), bootleg 90° turn (0.25 s), bootleg 180° turn (0.20 s), strong side turn (0.33 s), fleeing over shoulder (0.35 s), and fleeing under arm (0.31 s). In all situations involving fleeing, subsequent to shooting, the back overall was turned toward the LEO in 0.42 s ± 0.20 s (refer to Table 2 for each fleeing condition). As shown in Figure 1 (right panel), when peak hip extension of the right hip was achieved, it corresponded with peak hip flexion of the left hip, which would denote a neutral spine. Head turn, or neck rotation, was quantified during all fleeing situations. The head reached a neutral position in 0.24 s ± 0.13 s, when the assailant was facing directly (180°) away from the LEO. This was most likely as a result of a coordination of the head rotation with the running gait. The head then continued to over rotate an additional 35.6° ± 12.3° (0.18 s ± 0.13 s) to reach a maximum point or rotation. The head eventually returned to a neutral position as the assailant fled.

One artifact worth reporting was the elbow kinematics during the waistband shooting motion. In most trials, elbow kinematics displayed a reproducible dual-flexion profile (Double Hump profile); whereby the first elbow flexion corresponded with flexion toward the waistband to grip the weapon, and a second elbow flexion corresponded with the drawing of the weapon (see Top Panel, Figure 2). However it was not the case when the weapon was stuck in the waistband upon retrieval (Figure 2, Bottom Panel), which is described in detail in the discussion section (Figure 2).

Table 2: Summary statistics and reliability analysis (Intraclass Correlation Coefficient (ICC), Typical Error (TE) and Coefficient of Variation (CV) for the times to shoot and back turn (N=20). Results of parameter statistics are identified in the table with raised letters and footnoted for the three different shooting conditions.

	Time to shoot mean ± SD (s)	Test statistic	P-value	Effect size	Back turn (absolute) Mean ± SD (s)	Back turn (relative) Mean ± SD (s)	ICC alpha	SEM (s)	CV%
Stationary shooting	-	F=50.1	P<0.01	ηp2=0.72	-	-	-	-	-
Driver's side	0.50 ± 0.25a	-	-	-	N/A	N/A	0.9	0.08	18.1
Passenger's side	0.64 ± 0.29b	-	-	-	N/A	N/A	0.85	0.12	18.9
Waistband	1.13 ± 0.21	-	-	-	N/A	N/A	0.78	0.11	9.6
Shooting and fleeing	-	F=50.1	P<0.01	ηp2=0.72	-	-	-	-	-
Bootleg 90° turn	0.42 ± 0.12	-	-	-	0.83 ± 0.26	0.41 ± 0.19	0.88	0.04	9.9
Bootleg 180° turn	0.38 ± 0.11c	-	-	-	0.81 ± 0.28	0.43 ± 0.20	0.85	0.04	13.3
Strong side turn	0.49 ± 0.12d		-	-	0.90 ± 0.27	0.41 ± 0.20	0.44	0.11	24.4
Fleeing and shooting	-	F=0.09	P=0.99	ηp2=0.00	-	-	-	-	
Fleeing over shoulder	0.51 ± 0.14	-	-	-	0.92 ± 0.16	0.41 ± 0.21	0.61	0.11	28.6
Fleeing under arm	0.64 ± 0.22e	-	-	-	1.07 ± 0.23	0.43 ± 0.23	0.74	0.11	20.6

Note: [a]Significantly faster than waistband (t=11.03, p<0.01, d=2.74); [b]Signifcantly faster than waistband (t=6.20, p<0.01, d=1.92); [c]Significantly faster than boot leg 90° turn (t=4.77, p<0.01, d=0.35); [d]Significantly slower than 90° turn (t=5.18, p<0.01, d=0.58); and [e]Significantly slower than fleeing over shoulder (t=2.40, p=0.02, d=0.76).

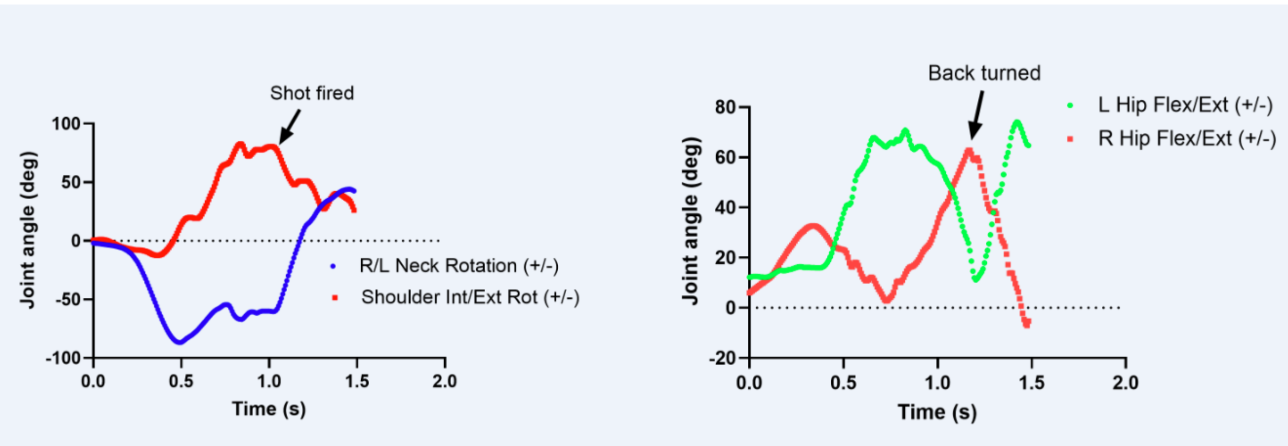

Figure 1: Kinematics of shot fired under the arm (Left Panel), and Back Turn (Right Panel). Note: Shot is occurring when peak shoulder internal rotation (left panel, red line) occurs while a static neck (left panel, blue line) is occurring simultaneously account for sighting in the officer. The back is completely turned to the officer when the hips are opposite of each other, with the right hip extended and the left hip flexed. This simulates a running motion, where the back is completely presented to the officer. **Note:** (•) L Hip Flex/Ext (+/-); (•) R Hip Flex/Ext (+/-).

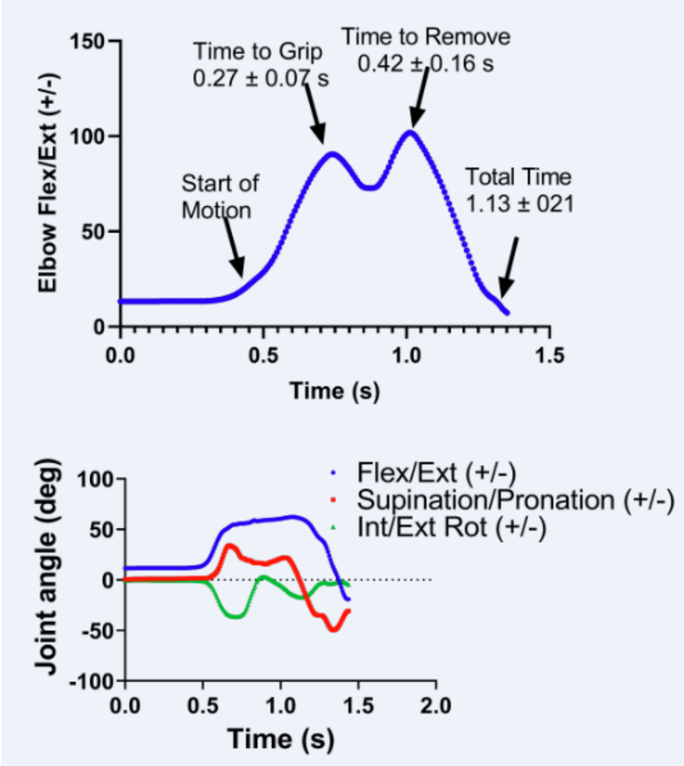

Figure 2: Kinematic profiles of the waistband draw and fire. The top panel depicts a characteristic double-hump appearance in elbow flexion, whereby, the initial hump depicts the time to flex the elbow to grip the weapon, a pause with slight elbow extension followed by a second hump to withdraw the weapon. The rapid extension is when the weapon is pointed and fired. The bottom panel depicts a slower subject's waistband draw performance whereby the double-hump is no longer present. For these subjects, we are portraying kinematics of the forearm (pronation/supination) along with shoulder internal/ external rotation. It would appear that when subjects experience the pistol getting stuck in the waistband, they may rely on forearm and shoulder rotary motions to help dislodge the weapon from the waistband. **Note:** (•) Flex/Ext (+/-); (•) Supination/Pronation (+/-); (▲) Int/Ext Rot (+/-).

Variability analysis of shooting motions

The variability analysis revealed that the three trials were highly consistent for many of the shooting conditions with greater variability observed for more dynamic actions (e.g., Strong-side condition, fleeing and shooting under the arm, and fleeing and shooting over the shoulder, see Table 2).

Differences between kinematic performances for each shooting category

Data met the assumptions for parametric statistical analysis. Significant differences ($p<0.01$) were observed between the three stationary shooting times, with the Driver's and Passenger's side time to shoot being faster than Waistband Draw (Table 2, first 3 rows) ($p<0.01$). Additionally, significant differences ($p<0.01$) were observed for the three shooting and fleeing conditions, with post hoc analyses presented in Table 2, rows 4, 5, and 6, with the Bootleg 90°. Finally, the time to shoot over the opposite shoulder while fleeing was significantly faster than the time to shoot under the opposite arm (Table 2, bottom two rows). No significant differences ($p=0.99$) for back turn times were found between each fleeing condition suggesting that the time to back turn didn't differ across the fleeing-related shooting conditions.

DISCUSSION

The present study evaluated the movement performance of younger males, between the ages of 18-37 years, who were naïve shooters and were asked to engage in eight common LEO shooting encounters. Despite being naïve shooters, all subjects were rapid and consistent in executing each maneuver as demonstrated by the range (0.50 to 1.13 s) of time to perform each of the shooting motion, which were similarto previous findings [12]. The current study included updated technology and was able to replicate these findings, confirming that naïve shooters, despite no formal training, can be fast in performing a firearm draw. These findings should enhance the understanding of time taken by untrained or naive shooters to draw a weapon during common shooting scenarios, potentially having implications for LEOs.

In the Stationary scenarios, the driver's-side motion was the fastest motion, and reported the highest degree of consistency compared to the passenger's-side, and waistband-draw motions. In all the stationary scenarios the target was six feet or closer (Driver's-side Scenario: three ft, Passenger's-side and Waistband Scenario: six ft). These findings suggest that if a LEO does not or cannot take pre-emptive to avoid or control the situation, they simply lack sufficient time to react and respond to the stimulus, prior to taking fire, which is supported by prior literature [7]. On average it was observed that it takes a LEO 0.37 ± 0.13 seconds to react to the threat (gun draw by driver) and a total time of 2.17 s ± 0.86 s to return fire [7]. This suggests that the LEO may react slower than even the slowest motion that was reported in our findings, i.e., the Waistband draw. These findings are further supported by the work of Lewinski, and Dysterheft, who reported typical stationary LEO gun draw performance times between 0.64 to 1.82 s for positions including the low ready, tactical low ready, close ready, shotgun in port, shotgun high ready, and Bootleg positions [16]. Based on these findings, LEOs may be placed at a risk of being in a position where they may or may not be able to respond promptly to a stationary threat. An improved chance of survival would be if the assailant's gun got stuck in the waistband, as observed in the current study, to provide some additional time to respond.

All of the shooting-then-fleeing scenarios indicated that the assailants were faster than the time for a LEO to react, decide and draw their weapon following a stimulus of lethal threat [7,16,17]. The time for the back to completely turn after the subjects' shot was approximately 0.4 s, and the neck over-rotated on average 35.6° when fleeing. Such a timeframe would make it conceivable for a responding LEO to discharge their weapon on a fleeing assailant's back or side of the head based on previous literature on LEO reaction time, decision-making time and trigger pull time, and draw time [7,18].

Most notably, the study by Lewinski, and Dysterheft on LEO trigger pull reaction time when the officer's weapon is drawn and held in a high-ready, sighted position found that reaction time to a light turned on was on average 0.25 s with 0.06 s trigger pull. When having to perform a trigger pull in response to a stimulus of either shoot/don't shoot situation, reaction time doubled to 0.56 s. When taking into account time to stop shooting once the shooting action was initiated, it took an additional 0.35 s. The LEO's time for decision-making and response to a threat of lethal force is critical to give context to the present study's fleeing back turn findings.

The fleeing-then-shooting motions demonstrated fast execution (0.51-0.64 s), but displayed the lowest level of consistency in our sample (Table 2) which may be attributed to the biomechanical complexities of these motions. For example, to execute a smooth motion in either shooting over or under the shoulder while fleeing, it was observed that the subjects needed to coordinate the movement of their dominant leg heel strike and peak shoulder internal rotation concurrently; otherwise, the torso was unable to fully rotate to point the gun and fire while fleeing. The duration and complexity of the action can potentially explain the reason for the higher level of variability in these motions. As expected for dynamic motions, even though these fleeing scenarios displayed the highest degree of variability, it was noted that both of the fleeing then shooting scenarios had an added advantage of concealing the weapon during the execution of the motion by having the back facing the target. Weapon-concealment allows for the individual to begin their shooting motion without the ability of the LEO to recognize a weapon being moved across the body to open fire. This delay of threat detection in back-facing scenarios would typically allow for a shorter decision-making timeframe for LEOs, making the consistency of the motion less valuable, as compared to the forward-facing scenarios.

LIMITATIONS

This study used a descriptive design and small sample to investigate the kinematic performance of naïve shooters, therefore, requiring caution when interpreting the results. However, this is one of the first studies to utilize kinematic instrumentation to describe a shooter's performance and characteristics in shooting scenarios which can potentially lay the necessary foundation for future research. Additionally, all the subjects included in the sample were all males between the ages of 18-37 years old, therefore limiting the generalizability of the kinematic performance outside of this demographic. Further studies with more comprehensive samples including a broad age range, and subjects from the opposite sex may be needed. Lastly, the gun fire was determined by kinematic markers as displayed in Table 1 and not upon the trigger pull, as seen in the report by Lewinski. However, the termination of each motion in this study was determined when the firearm was pointed directly at the target. Despite the differences in methodology, the results for both studies were similar. Therefore, the results from this study still provide empirical data on the speed and variability of common shooting scenarios in a small young and naïve sample. The times in this study with movements that involved running were slightly slower than other studies. This may be a result of the smaller laboratory in which this study was conducted.

CONCLUSION

The present study examined the time taken by naïve shooters to shoot in eight common shooting motions involving the UoF with LEOs. To our knowledge, this is the first movement analysis study to provide temporal and kinematic details of these actions from an assailant's perspective. The rapid execution and consistency to shoot (<1.13 seconds), and turn to flee (~0.4 s) provides a basis for understanding how dynamic these encounters are for LEOs. Implications of the kinematics draw time, back and head turn findings are discussed in this study. Future investigations are warranted to confirm possible training and legal applications of these findings.

DECLARATION

Conflict of interests

None

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