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ORIGINAL ARTICLE

Injury potential of thrown sharp kitchen and household utensils

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Abstract

We examined the possibility of inflicting serious injuries with sharp objects in an experimental setting by throwing four sharp objects from different distances and with different throwing techniques. Using an overarm-handle (OA/H), overarm-blade (OA/B), underarm-handle (UA/H), underarm-blade (UA/B) and thrust (T/H) throwing technique, 10 adults (sex ratio 1:1) threw a chef's knife, a skinning knife, a paring knife and office scissors from 4 m and 2 m distance at synthetic abdomen models made of 10% gelatin covered with synthetic skin. The amount of hits and penetrations of the target and their penetration depth were noted, as was the rotation of the blade tip towards the target along its flight trajectory. The chef's knife injury/hit ratio was 0.167/4 m and 0.160/2 m; the skinning knife recorded an injury/hit ratio of 0.087/4 m and 0.153/2 m; the paring knife of 0.087/4 m and 0.113/2 m; and the scissors 0.087/4 m and 0.067/2 m. Mean penetration depths were as follows: the chef's knife: 4 m, 4.42 cm, 2 m, 3.41 cm; the skinning knife: 4 m, 4.19 cm, 2 m, 4.11 cm; the paring knife: 4 m, 1.62 cm, 2 m, 1.55 cm; and the scissors: 4 m, 2.08 cm, 2 m, 0.95 cm. Handle-throw penetration-depths were: 4 m: 3.77 cm and 2 m: 2.86 cm; blade-throw depths were: 4 m: 3.14 cm and 2 m: 2.69 cm. Overarm-throw penetration-depths were: 4 m: 3.62 cm and 2 m: 3.25 cm; and underarm-throw penetration-depths were 4 m: 3.30 cm and 2 m: 2.30 cm. No thrust-throws with the paring knife and scissors could pierce the target. The tips pointed toward the target at angles of 60°-120°, earlier in handle-throws than blade-throws, especially with the paring knife and the scissors. When thrown, especially with a handle-held technique, heavier objects pierced more often and more deeply. Thrust-throws at short distances are unlikely to pierce a human.

Keywords Throwing technique · Piercing injury · Knife · Scissors · Synthetic model · Forensic

Introduction

In physical disputes, stab injuries are frequently encountered. Based on our experiences, the most frequent objects or weapons inflicting these injuries are knives, followed by scissors and glass shards, and usually, these sharp objects are stabbed at the victim. Several authors have examined the forces necessary for penetrating skin and soft tissue [1–4], ribs [5] and clothing [6]. Besides stabbing, which implies that a sharp-edged or pointed instrument is actively jabbed at the victim, cases of alleged accidental injury occur by, for example, bumping into a knife. However, that scenario is not entirely comparable to stabbing, as the movement is mostly generated by the victim, which has been described in the literature [7]. Other claims made by defendants were that a sharp object had been thrown and accidentally hit and injured the victim. Sterzik et al. examined such a scenario involving shards from a broken glass table [8] and thrown drinking glasses [9] and O'Callaghan et al. described a case of a thrown glass shard [10].

Muggenthaler et al. performed experiments on the base of various claims examining the throwing technique of a knife in a case of domestic violence in which the victim suffered a 1.8 cm long and approximately 3 cm deep injury to the nape [11]. Their study examined the possibility of such an injury being inflicted upon a pig carcass by either throwing a knife at it from a distance of 1 m, by letting a knife slip out of the hand from the same distance, or by stabbing it with the same knife. At 1 m distance, the knife only stuck if thrown by initially holding it by the handle. An initially blade-held throw failed to lead to an injury, as did the "slipping out of the hand" scenario.

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We too have occasionally encountered cases of domestic violence in which the defendants claimed that the injury was caused by a knife accidentally slipping out of the hand. In one such case, a woman apparently erratically flung the contents of a kitchen drawer containing table cutlery, a chef's knife and scissors in thrust-like fashion at her boyfriend from roughly 2 m distance. In the course of this, the young man suffered a 12 cm deep penetrating wound to the abdomen by the chef's knife, deeply piercing the liver. In the light of such incidents, we asked ourselves how likely it would be that a person unaccustomed to knife-throwing could deliberately hit and cause injury to a target the size of a human torso using different sharp objects. If so, we further wondered, how deep would the blade penetrate, and finally, to what extent would the severity of the injury be influenced by different projectiles, such as the chef's knife, the skinning knife, the paring knife or the office scissors used in the previously mentioned case. In order to answer these questions, we undertook a study that simulated injuries to a human torso caused by persons unaccustomed to knife-throwing and using different throwing techniques to pitch various household projectiles at the torso from 4 m or 2 m distance.

The aim of this study was to assess (1) the number of throws hitting a target the size of a human torso by persons without experience in knife-throwing at a distance of 2 m and 4 m, (2) the number of injuries occurring in relation to the hits and throws, (3) the penetration depths if the blade pierced a human abdomen model (synthetic skin and underlying gelatin) and (4) the flight characteristics and the potential risk of injury at several distances ranging from 0.5 to 3.5 m using four different objects and five different throwing methods.

Method and materials

Throwers

Ten adults ($n = 10$, mean age: 32.8 ± 5.7 y, mean weight: 69.7 ± 14.6 kg, mean size: 171.1 ± 7.7 cm; female: $n = 5$, mean age: 30.4 ± 3.2 y, mean weight: 59.0 ± 13.1 kg, mean size: 167.0 ± 7.4 cm; male: n = 5, mean age: 35.2 ± 6.9 y, mean weight: 80.4 ± 4.5 kg, mean size: 175.2 ± 6.1 cm) were requested to throw four objects using five different throwing techniques from 4 m as well as 2 m distance at a fully synthetic abdomen model. None of these test persons had any mentionable experience in knife-throwing.

Objects and throwing methods

The four thrown objects were a chef's knife (weight: 180 g, total length: 38 cm, blade length: 20 cm), a skinning knife (weight: 120 g, total length: 30 cm, blade length: 14 cm), a paring knife (weight: 30 g, total length: 21 cm, blade length:

Fig. 1 The four thrown objects were a chef's knife (**a**: weight: 180 g, total length: 38 cm, blade length: 20 cm), a skinning knife (**b**: weight: 120 g, total length: 30 cm, blade length: 14 cm), a paring knife (**c**: weight: 30 g, total length: 21 cm, blade length: 10 cm) and a pair of office scissors (**d**: weight: 40 g, total length: 21 cm, blade length: 13 cm)

10 cm) and office scissors (weight: 40 g, total length: 21 cm, blade length: 13 cm) (Fig. 1).

The objects were thrown at the target from distances of 4 m and 2 m using the following methods (Fig. 2):

- Overarm, holding the handle (OA/H)
- Overarm, holding the blade (OA/B)
- Underarm, holding the handle (UA/H)
- Underarm, holding the blade (UA/B)
- Horizontal thrust, holding the handle (T/H)

Target

The abdomen model was made as follows: A 10% gelatin solution was made using ordnance gelatin powder (Type 3 Photographic Grade, GELITA AG, Uferstr. 7, 69,412 Eberbach, Germany) as described previously [12] and then filled into a wooden crate (54 × 53 cm). After hardening, the gelatin block was covered by synthetic skin made of 4.2 mm thick silicone ecoflex, shore 0-3A (00–30) (Synbone soft tissue pad, PR1043.10, Synbone AG Malans, 7208 Malans, Switzerland), which was attached to the gelatin with needles. The crate was set upright in order to position the synthetic skin surface facing towards the thrower.

Experimental set-up and data acquisition

The thrower's position was such that the outstretched arm was either 2 m or 4 m away from the target, respectively. For a specific throwing technique and distance each test person was required to throw as many times as necessary until he or she had hit the target three times (hits overall: $n = 1200$, at 4 m: $n = 600$, at 2 m n = 600; hits per thrower: n = 120, hits per object: $n = 300$, hits per throwing method: $n = 240$). A hit was considered valid even if the blade did not pierce the target (for example, if the butt of a handle struck the target). To avoid self-injury each thrower wore cut resistant gloves for throwing techniques requiring a blade-grip. All throws were filmed in slow motion (240 frames per second) by a standard camera. To measure the distances in the recordings of the objects on their flight trajectory towards the target, a paper strip of alternating black and white color margining 50 cm intervals was stuck onto the wall along and parallel to the flight track, starting at 4 m and ending at the target.

The study supervisor recorded the total numbers of throws and injuries per individual throwing method, object and test person, namely whether the blade pierced the synthetic skin and the underlying gelatin mass or not. Based on this data the hit/throw, injury/hit and injury/throw ratios were calculated for each test person with respect to each object and each throwing method at the distances of 2 m and 4 m. Further, the penetration depths by the instruments in the target were measured and noted. The penetration depth was assessed by either measuring the depth of a blade remaining stuck in the target or, in the case of the instrument falling off the target, the extent of the greasy gelatin residues on the blade. Blades were wiped clean of gelatin residues prior to the next throw.

Apart from assessing the blades' actual hitting and piercing into the target from the distances of 2 m and 4 m for each

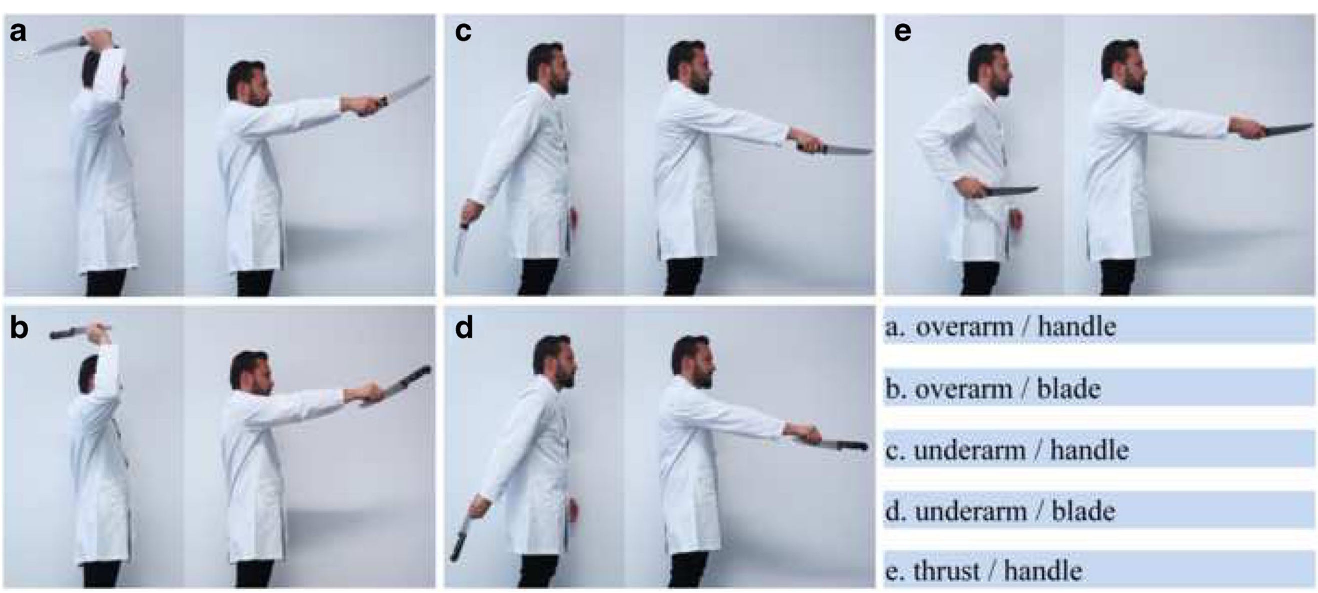

Fig. 2 The four objects were thrown at 4 m and 2 m distances to the target using five different throwing methods, namely overarm by holding the handle (**a**), overarm by holding the blade (**b**), underarm by holding the handle (**c**), underarm by holding the blade (**d**) and horizontal thrust by holding the handle (**e**). The image pairs display the posture to take the swing (left images) and the posture immediately before opening the hand (right images). The test person demonstrates the throws using the chef's knife

object, throwing technique and individual test person, and their rotational movement along their flight path were noted, as well by using the slow-motion film sequences and retrospectively measuring the angles at the defined distances of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 m from the target. A blade tip hitting the target horizontally was defined as 90°, 180° if it faced the floor vertically, and so on, clockwise. An angle of 60° to 120° was defined as being potentially harmful – as the knives' tips in these cases directly pointed towards the target and thus would have had the capability of penetrating it. The number of these potential injuries was noted and accordingly the potential injury/hit ratios of all individual objects, throwing methods and throwing participants were calculated for the distances of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 m.

Statistical analyses

The t-test was used to detect statistical significances between 4 m and 2 m and between male and female throwers regarding the number of throws. According to the results of the Levene test, a one–way analysis of variance (ANOVA) or the Welch F test (if the homogeneity of variances was violated) was used to detect statistical significances between the objects, between the throwing methods, between the number of throws and between the distances of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 m. Furthermore, the Tukey's honestly significant difference (HSD) or the Games-Howell (if the homogeneity of variances was violated) post hoc test was performed. The significance level was set to 0.05. Statistical analyses were performed using dedicated statistical software (IBM SPSS Statistics, Version 24, Armonk, NY, USA).

Results

A total of 2244 throws (chef's knife: $n = 572$; skinning knife: $n = 536$; paring knife: $n = 612$; scissors: $n = 524$) were performed and a total number of 138 piercings ($n = 138$; Chef's knife: $n = 49$; skinning knife: $n = 36$; paring knife: $n = 30$; scissors: $n = 23$) were noted. No piercings were recorded for the light objects using the T/H method at both distances, nor for the paring knife using the UA/B method at 2 m. The overall mean value was 0.639 for the hit/throw ratio, 0.115 for the injury/hit ratio and 0.073 for the injury/throw ratio. At 4 m a total of 1323 throws (chef's knife: $n = 328$; skinning knife: $n = 304$; paring knife: $n = 375$ scissors: $n = 316$) were performed with a total number of 64 piercings (chef's knife: $n = 25$; skinning knife: $n = 13$; paring knife: n = 13 scissors: n = 13). At 2 m a total of 921 throws (chef's knife: $n = 244$; skinning knife: $n = 232$; paring knife: $n = 237$ scissors: $n = 208$) were performed with a total number of 74 piercings (chef's knife: n = 24; skinning knife: n = 23; paring knife: $n = 17$ scissors: $n = 10$). At 4 m the overall mean value was 0.546 for the hit/throw ratio, 0.107 for the injury/hit ratio and 0.057 for the injury/throw ratio. At 2 m the overall mean value was 0.732 for the hit/throw ratio, 0.123 for the injury/hit ratio and 0.089 for the injury/throw ratio. The mean values of the hit/throw ratio, the injury/hit ratio, the injury/throw ratio are listed in Table 1 and the penetration depth in Table 2. The rankings from the highest to the lowest overall mean values are listed in Table 3.

Hit/Throw

The overall mean hit/throw values at 4 m were lower than the overall mean values at 2 m. At 4 m the skinning knife

Table 1 The mean values of the hit/throw, the injury/hit and the injury/throw ratios

Distance			4 m						2 m						
Throws			242	251	263	314	253	1323	179	199	183	210	150	921	2244
	Object	Ratio	OA/H	OA/B	UA/H	UA/B	T/H	Mean (4 m)	OA/H	OA/B	UA/H	UA/B	T/H	Mean (2 m)	Overall mean
572	Chef's knife	hit/throw	0.528	0.446	0.455	0.631	0.650	0.542	0.740	0.587	0.728	0.653	0.843	0.710	0.626
		injury/hit	0.167	0.233	0.100	0.233	0.100	0.167	0.067	0.333	0.200	0.067	0.133	0.160	0.163
		injury/throw	0.072	0.118	0.045	0.174	0.057	0.093	0.037	0.195	0.137	0.053	0.133	0.111	0.102
536	Skinning knife	hit/throw	0.629	0.653	0.737	0.421	0.586	0.605	0.810	0.663	0.703	0.535	0.885	0.719	0.662
		injury/hit	0.033	0.067	0.167	0.100	0.067	0.087	0.200	0.300	0.033	0.100	0.133	0.153	0.120
		injury/throw	0.011	0.024	0.086	0.064	0.053	0.048	0.133	0.230	0.017	0.045	0.092	0.103	0.076
612	Paring knife	injury/throw	0.636	0.581	0.519	0.420	0.382	0.507	0.698	0.666	0.725	0.610	0.803	0.700	0.604
		injury/hit	0.100	0.100	0.067	0.167	0.000	0.087	0.200	0.267	0.100	0.000	0.000	0.113	0.100
		injury/throw	0.087	0.033	0.029	0.055	0.000	0.041	0.157	0.195	0.083	0.000	0.000	0.087	0.064
524	Scissors	injury/throw	0.614	0.613	0.467	0.456	0.489	0.528	0.670	0.870	0.810	0.740	0.910	0.800	0.664
		injury/hit	0.100	0.200	0.067	0.067	0.000	0.087	0.033	0.167	0.033	0.100	0.000	0.067	0.077
		injury/throw	0.039	0.125	0.026	0.034	0.000	0.045	0.033	0.153	0.020	0.073	0.000	0.056	0.050
2244	Overall mean	hit/throw	0.602	0.573	0.544	0.482	0.527	0.546	0.730	0.696	0.741	0.635	0.860	0.732	0.639
		injury/hit	0.100	0.150	0.100	0.142	0.042	0.107	0.125	0.267	0.092	0.067	0.067	0.123	0.115
		injury/throw	0.052	0.075	0.046	0.082	0.028	0.057	0.090	0.193	0.064	0.043	0.056	0.089	0.073

This table shows the mean hit/throw, the mean injury/hit and the mean injury/throw ratio of all ten throwers for each object and each throwing method at 2 m and 4 m

Table 2 The mean, the minimum and the maximum penetration depth in cm

Distance			4 m						2 m						
Piercings			12	18	12	17	5	64	15	32	11	8	8	74	138
	Object	Depth	OA/H	OA/B	UA/H	UA/B	T/H	Mean 4 m	OA/H	OA/B	UA/H	UA/B	T/H	Mean 2 m	Overall mean
49	Chef's knife	mean	5.80	3.31	6.00	3.00	4.00	4.42	5.50	3.85	2.47	3.25	2.00	3.41	3.92
		minimum	3.00	1.00	4.50	0.50	1.50	2.10	2.00	0.50	0.50	1.00	0.00	0.80	1.45
		maximum	8.50	6.50	8.50	7.00	5.50	7.20	9.00	7.50	3.00	5.50	3.00	5.60	6.40
36	Skinning knife	mean	5.50	5.50	5.20	2.50	2.25	4.19	5.42	3.39	4.00	4.00	3.75	4.11	4.15
		minimum	5.30	4.00	2.00	0.50	1.50	2.66	1.00	0.50	3.80	3.50	0.50	1.86	2.26
		maximum	5.70	7.00	8.00	5.00	3.00	5.74	8.00	7.00	4.20	4.50	6.50	6.04	5.89
30	Paring knife	mean	1.43	2.00	2.40	2.26	0.00	1.62	2.50	3.25	2.00	0.00	0.00	1.55	1.58
		minimum	0.80	0.50	0.80	0.80	0.00	0.58	0.50	2.00	1.00	0.00	0.00	0.70	0.64
		maximum	2.00	4.50	4.00	4.00	0.00	2.90	4.00	5.00	3.00	0.00	0.00	2.40	2.65
23	Scissors	mean	2.83	2.58	1.00	4.00	0.00	2.08	0.50	1.60	0.50	2.17	0.00	0.95	1.52
		minimum	2.50	0.50	0.80	2.00	0.00	1.16	0.80	1.00	0.70	1.50	0.00	0.80	0.98
		maximum	3.00	8.00	1.30	6.00	0.00	3.66	0.30	4.00	0.30	3.00	0.00	1.52	2.59
138	Overall mean	mean	3.89	3.35	3.65	2.94	1.56	3.08	3.48	3.02	2.24	2.35	1.44	2.51	2.79
		minimum	2.90	1.50	2.03	0.95	0.75	1.63	1.08	1.00	1.50	1.50	0.13	1.04	1.33
		maximum	4.80	6.50	5.45	5.50	2.13	4.88	5.33	5.88	2.63	3.25	2.38	3.89	4.38

This table shows the mean, the minimum and the maximum penetration depth of all ten throwers for each object and each throwing method at 2 m and 4 m

yielded the highest mean value; by contrast, at 2 m the scissors presented the highest mean value. At 4 m the mean hit/throw value of heavy instruments was higher than the corresponding value of the light instruments. At 2 m distance, however, the mean hit/throw value of the light objects was higher than that of the heavy objects. The OA/H method demonstrated the highest mean value at 4 m; by contrast, at 2 m the T/H method yielded the highest mean value. The mean hit/throw ratios for handle-grip throwing methods were higher than the mean hit/throw ratios for blade-grip throwing methods. The mean hit/throw ratio for overarm throws was higher than the mean hit/throw ratio for underarm throws.

Injury/Hit

The overall mean injury/hit values at 4 m were lower than the overall mean values at 2 m but the mean values of the chef's knife and the scissors, as well as the overall mean values of the UA/H and UA/B method, were higher at 4 m than at 2 m. At 4 m the chef's knife yielded the highest mean value, followed by all other objects with equivalent mean values. The highest mean value at 2 m was also detected for the chef's knife. The overall mean injury/hit ratio of the heavy objects was higher than the overall mean injury/hit ratio of the light objects at 4 m and at 2 m. At 4 m and at 2 m the OA/B throwing method demonstrated the highest mean value. and the mean injury/hit ratio for overarm throws was higher than the mean injury/hit ratio for underarm throws.

Injury/Throw

The overall mean values at 4 m were lower than the overall mean values at 2 m but the overall mean values of UA/B method. At 4 m and at 2 m the highest mean value of the injury/throw ratio was detected for the chef's knife and the mean injury/throw ratios of the heavy objects were higher than the mean injury/throw ratios of the light objects. The highest overall mean value at 4 m was detected for the UA/B method; by contrast, at 2 m the highest overall mean value was detected for the OA/B method. In contrast to the hit/throw ratios, the mean injury/hit ratios at 4 m and at 2 m were higher for the blade-grip throwing methods than the mean injury/hit ratios for handle-grip throwing methods. The mean injury/throw ratio for overarm throws at 2 m was higher than the mean injury/throw ratio for underarm throws at 2 m. At 4 m the injury/throw ratios between overarm and underarm throws were equivalent (0.064).

Penetration depth

The mean depths at 4 m were higher than the mean depths at 2 m. At both distances the highest maximum depth was measured for the Chef's knife at 4 m (8.5 cm) using the OA/H and the UA/H method and at 2 m (9.0 cm) using the OA/H method. The highest mean value at 4 m was detected for the chef's knife. At 2 m the skinning knife yielded the highest mean value. The mean depth of the heavy objects was higher than the mean depth of the light objects at 4 m and at 2 m. The highest overall mean depth at 4 m and at 2 m was detected for the OA/H throwing method. At both

Table 3 The rankings from highest to lowest overall mean values

Hit/Throw						Injury/Hit					
Ranking	4 m	Overall mean	Ranking	2 m	Overall mean	Ranking	4 m	Overall mean	Ranking	2 m	Overall mean
1	Skinning knife	0.605	1	Scissors	0.800	1	Chef's knife	0.167	1	Chef's knife	0.160
2	Chef's knife	0.542	2	Skinning knife	0.719	2	Skinning knife	0.087	2	Skinning knife	0.153
3	Scissors	0.528	3	Chef's knife	0.710	2	Paring knife	0.087	3	Paring knife	0.113
4	Paring knife	0.507	4	Paring knife	0.700	2	Scissors	0.087	4	Scissors	0.067
1	heavy	0.574	1	light	0.750	1	heavy	0.127	1	heavy	0.157
2	light	0.518	2	heavy	0.715	2	light	0.088	2	light	0.090
1	OA/H	0.602	1	T/H	0.860	1	OA/B	0.150	1	OA/B	0.267
2	OA/B	0.573	2	UA/H	0.741	2	UA/B	0.142	2	OA/H	0.125
3	UA/H	0.544	3	OA/H	0.730	3	UA/H	0.100	3	UA/H	0.092
4	T/H	0.527	4	OA/B	0.696	3	OA/H	0.100	4	UA/B	0.067
5	UA/B	0.482	5	UA/B	0.635	5	T/H	0.042	4	T/H	0.067
1	handle	0.573	1	handle	0.735	1	blade	0.146	1	blade	0.167
2	blade	0.528	2	blade	0.666	2	handle	0.100	2	handle	0.110
1	overarm	0.587	1	overarm	0.713	1	overarm	0.125	1	overarm	0.196
2	underarm	0.513	2	underarm	0.688	2	underarm	0.121	2	underarm	0.079

Injury/Throw						Penetration depth(cm)					
Ranking	4 m	Overall mean	Ranking	2 m	Overall mean	Ranking	4 m	Overall mean	Ranking	2 m	Overall mean
1	Chef's knife	0.093	1	Chef's knife	0.111	1	Chef's knife	4.42	1	Skinning knife	4.11
2	Skinning knife	0.048	2	Skinning knife	0.103	2	Skinning knife	4.19	2	Chef's knife	3.41
3	Scissors	0.045	3	Paring knife	0.087	3	Scissors	2.08	3	Paring knife	1.55
4	Paring knife	0.041	4	Scissors	0.056	4	Paring knife	1.62	4	Scissors	0.95
1	heavy	0.070	1	heavy	0.107	1	heavy	4.31	1	heavy	3.76
2	light	0.043	2	light	0.071	2	light	1.85	2	light	1.25
1	UA/B	0.082	1	OA/B	0.193	1	OA/H	3.89	1	OA/H	3.48
2	OA/B	0.075	2	OA/H	0.090	2	UA/H	3.65	2	OA/B	3.02
3	OA/H	0.052	3	UA/H	0.064	3	OA/B	3.35	3	UA/B	2.35
4	UA/H	0.046	4	T/H	0.056	4	UA/B	2.94	4	UA/H	2.24
5	T/H	0.028	5	UA/B	0.043	5	T/H	1.56	5	T/H	1.44
1	blade	0.078	1	blade	0.118	1	handle	3.77	1	handle	2.86
2	handle	0.049	2	handle	0.078	2	blade	3.14	2	blade	2.69
1	overarm	0.064	1	overarm	0.142	1	overarm	3.62	1	overarm	3.25
1	underarm	0.064	2	underarm	0.053	2	underarm	3.30	2	underarm	2.30

The rankings of the highest (rated as 1) to the lowest overall mean values revealed that the chef's and the skinning knife are most effective (hit/throw and injury/throw ratio) and dangerous (injury/hit and penetration depth) objects at both distances but at 2 m the scissors yielded the highest overall mean hit/throw ratio. The OA/B methods demonstrated the highest overall mean injury/hit ratios but the OA/H method yielded the highest overall mean penetration depth distances, the overall mean depth achieved by handle-grip was higher than the overall mean depth of the blade-grip throws. The overarm throws at 4 m and at 2 m yielded higher mean values than underarm throws.

Potential injury/hit

The mean potential injury/hit ratio of each object and each throwing method over the distance of 0.5 to 3.5 m are listed in Table 4. The ranking of the potential injury/hit mean values are listed in Table 5. The scissors yielded the highest mean value at 0.5 m and the second highest at 1 m. At all other distances the scissors were ranked last. At all distances from 1 to 3 m the chef's knife yielded the highest mean value. At 3.5 m the skinning knife was ranked first followed by the chef's knife. The T/H throwing method was most effective at 0.5 m whereas at 2 m the T/H method was ranked last for all distances up to 3.5 m. At 1 m the OA/H, at 1.5 m the UA/B, at 2 m the OA/B and at 2.5 m the UA/H method was ranked first. Again at 3 m the OA/H and at 3.5 m the UA/B method was ranked first. The ratios between heavy and light objects, handle grip and blade grip, overarm and underarm throws over the distance of 0.5 to 3.5 m are shown in Table 5. The light objects only demonstrated a higher overall mean value at 0.5 m, whereas the heavy objects yielded higher mean values at all distances. At 0.5 m and 1 m the handle-grip throws exhibited higher mean values than blade grip throws. At every meter handle-grip and blade-grip throws switched positions in the ranking. By contrast overarm throws and underarm throws switched their ranking every half meter. At 0.5, 1.5 and 3.5 m the underarm throws yielded higher mean values, in turn, at 1, 2 and 3 m the overarm throws showed higher mean values.

Statistical anlysis

Statistically significant differences were detected between 4 m and 2 m in general (hit/throw: $p < 0.001$; injury/throw: $p = 0.026$), between 4 m and 2 m for the throwing methods (hit/throw: OA/H: $p = 0.020$, OA/B: $p = 0.007$, UA/H: $p < 0.001$, UA/B: $p = 0.002$ and T/H: $p < 0.001$; injury/throw: OA/B: $p = 0.007$) and between 4 m and 2 m for the objects (hit/throw: chef's knife: $p = 0.001$, skinning knife: $p = 0.019$, paring knife: $p < 0.001$, scissors: $p < 0.001$).

Furthermore, statistical analyses revealed significant differences between heavy and light objects (injury/hit at 2 m: $p = 0.036$), between handle-throws and blade-throws (hit/throw at 2 m: $p = 0.049$), between overarm and underarm throwing (hit/throw at 4 m: $p = 0.046$; injury/hit at 2 m: $p = 0.002$; injury/throw at 2 m: $p = 0.001$) and between the throwing methods (hit/throw at 2 m: $p < 0.001$, injury/hit at 2 m: $p = 0.004$, injury/throw at 2 m: $p = 0.007$). The mean hit/throw ratio was statistically significantly lower for the OA/B ($p = 0.008$) and UA/B ($p < 0.001$) method compared to the mean hit/throw ratio of the T/H method. In contrast, the injury/hit and injury/throw ratio were statistically significantly lower for

Table 4 The mean values of the potential injury/hit ratios of all distances

Object	Throwing method	50 cm	100 cm	150 cm	200 cm	250 cm	300 cm	350 cm	Overall mean
Chef's knife	OA/H	0.154	0.433	0.077	0.208	0.033	0.267	0.183	0.194
	OA/B	0.100	0.058	0.221	0.225	0.242	0.233	0.150	0.176
	UA/H	0.488	0.304	0.275	0.292	0.313	0.125	0.167	0.280
	UA/B	0.000	0.017	0.167	0.037	0.296	0.259	0.111	0.127
	T/H	0.745	0.403	0.213	0.125	0.125	0.125	0.125	0.266
	Mean	0.297	0.243	0.190	0.177	0.202	0.202	0.147	0.208
Skinning knife	OA/H	0.308	0.383	0.079	0.225	0.333	0.233	0.050	0.230
	OA/B	0.083	0.075	0.189	0.283	0.050	0.233	0.200	0.159
	UA/H	0.423	0.331	0.129	0.050	0.168	0.115	0.187	0.200
	UA/B	0.050	0.042	0.317	0.130	0.130	0.148	0.315	0.162
	T/H	0.639	0.301	0.194	0.063	0.063	0.063	0.125	0.207
	Mean	0.301	0.226	0.182	0.150	0.149	0.158	0.175	0.192
Paring knife	OA/H	0.333	0.267	0.100	0.167	0.167	0.183	0.125	0.192
	OA/B	0.010	0.071	0.142	0.225	0.125	0.150	0.133	0.122
	UA/H	0.592	0.104	0.104	0.067	0.225	0.192	0.233	0.217
	UA/B	0.083	0.100	0.300	0.117	0.067	0.100	0.150	0.131
	T/H	0.426	0.324	0.148	0.037	0.037	0.093	0.037	0.157
	Mean	0.289	0.173	0.159	0.122	0.124	0.144	0.136	0.164
Scissors	OA/H	0.370	0.250	0.019	0.037	0.185	0.111	0.148	0.160
	OA/B	0.046	0.176	0.227	0.146	0.063	0.146	0.125	0.133
	UA/H	0.481	0.324	0.074	0.104	0.125	0.125	0.063	0.185
	UA/B	0.037	0.130	0.250	0.222	0.037	0.037	0.148	0.123
	T/H	0.694	0.296	0.222	0.071	0.048	0.000	0.000	0.190
	Mean	0.326	0.235	0.158	0.116	0.091	0.084	0.097	0.158
Overall mean		0.303	0.219	0.172	0.142	0.142	0.147	0.139	0.181

The potential injury/hit ratio was much higher at 0.5 and 1 m compared to the other distances. With 2 m the overall mean values are almost equal. Over all distances the chef's knife yielded the highest overall mean value followed by the skinning knife, the paring knife and the scissors

Table 5 The rankings from highest to lowest overall mean potential injury/hit values

Potential injury/Hit

Ranking	0.5 m	Overall mean	Ranking	1 m	Overall mean	Ranking	1.5 m	Overall mean	Ranking	2 m	Overall mean
1	Scissors	0.326	1	Chef's knife	0.243	1	Chef's knife	0.190	1	Chef's knife	0.177
2	Skinning knife	0.301	2	Scissors	0.235	2	Skinning knife	0.182	2	Skinning knife	0.150
3	Paring knife	0.289	3	Skinning knife	0.226	3	Paring knife	0.159	3	Paring knife	0.122
4	Chef's knife	0.297	4	Paring knife	0.173	4	Scissors	0.158	4	Scissors	0.116
1	light	0.307	1	heavy	0.235	1	Heavy	0.186	1	heavy	0.164
2	heavy	0.299	2	light	0.204	2	Light	0.159	2	light	0.119
1	T/H	0.626	1	OA/H	0.333	1	UA/B	0.258	1	OA/B	0.220
2	UA/H	0.496	2	T/H	0.331	2	OA/B	0.195	2	OA/H	0.159
3	OA/H	0.292	3	UA/H	0.266	3	T/H	0.194	3	UA/B	0.128
4	OA/B	0.060	4	UA/B	0.072	4	UA/H	0.146	4	UA/H	0.126
5	UA/B	0.043	5	OA/B	0.095	5	OA/H	0.069	5	T/H	0.074
1	handle	0.394	1	handle	0.300	1	Blade	0.226	1	blade	0.173
2	blade	0.051	2	blade	0.084	2	Handle	0.107	2	handle	0.144
1	underarm	0.269	1	overarm	0.214	1	Underarm	0.202	1	overarm	0.190
2	overarm	0.176	2	underarm	0.169	2	Overarm	0.132	2	underarm	0.127

Potential injury/Hit

Ranking	2.5 m	Overall mean	Ranking	3 m	Overall mean	Ranking	3.5 m	Overall mean
1	Chef's knife	0.202	1	Chef's knife	0.202	1	Skinning knife	0.175
2	Skinning knife	0.149	2	Skinning knife	0.158	2	Chef's knife	0.147
3	Paring knife	0.124	3	Paring knife	0.144	3	Paring knife	0.136
4	Scissors	0.091	4	Scissors	0.084	3	Scissors	0.097
1	heavy	0.175	1	heavy	0.180	1	heavy	0.161
2	light	0.108	2	light	0.114	2	light	0.116
1	UA/H	0.208	1	OA/H	0.208	1	UA/B	0.181
2	OA/H	0.180	2	OA/B	0.180	2	UA/H	0.162
3	UA/B	0.135	3	UA/H	0.132	3	OA/B	0.152
4	OA/B	0.132	4	UA/B	0.120	4	OA/H	0.127
5	T/H	0.068	5	T/H	0.068	5	T/H	0.072
1	handle	0.194	1	handle	0.169	1	blade	0.144
2	blade	0.126	2	blade	0.163	2	handle	0.167
1	underarm	0.170	1	overarm	0.195	1	underarm	0.172
2	overarm	0.150	2	underarm	0.138	2	overarm	0.139

At 0.5 and 1 m, the scissors achieved a high ranking, but with 2 m or more, they ranked last. At 1 m, the chef's and the skinning knife, thus the heavy objects, ranked highest. The T/H method seemed to be dangerous solely from 0.5 to 1.5 m. The highest rank of the most dangerous throwing technique that caused a rotation of the blade changed between 0.5 and 2 m with every half meter. The sequence of the most dangerous throw technique repeated at 2.5 m

the UA/H (injury/hit: $p = 0.015$; injury/throw: ($p = 0.020$), UA/B (injury/hit: $p = 0.003$; injury/throw: $p = 0.003$) and the T/H (injury/hit: $p = 0.004$; injury/throw: $p = 0.018$) method compared to the injury/hit ratio of the OA/B method.

The number of throws necessary to achieve three hits was not statistically significantly different between female and male throwers at either 2 m or at 4 m. However, the number of throws between all raters was statistically significant at both distances (4 m: $p < 0.001$, 2 m: $p = 0.023$).

Regarding the potential injury/throw ratio, statistically significant differences were detected between all distances ($p < 0.001$). The potential injury/hit ratio was statistically significantly lower at 1.5 m ($p = 0.039$), at 2 m ($p = 0.039$), at 2.5 m ($p = 0.011$), at 3 m ($p = 0.005$) and at 3.5 m ($p = 0.014$) compared to the potential injury/hit ratio at 0.5 m. Further, there was a statistically significant difference between distances for the potential injury/hit ratio of the scissors ($p = 0.001$). The potential injury/hit ratio of the scissors was statistically significantly lower at 2 m ($p = 0.039$), at 2.5 m ($p = 0.011$), at 3 m ($p = 0.005$) and at 3.5 m ($p = 0.014$) compared to potential injury/hit ratio of 0.5 m.

Discussion

This study revealed (according to the overall mean values at 4 m and at 2 m) that 54.6% at 4 m and 73.2% at 2 m of all throws hit the target but only 5.7% at 4 m and 8.9% at 2 m of all throws caused a sharp force injury. Furthermore, 10.7% of all hits caused an injury at 4 m and 12.3% at 2 m. The average penetration depth at 4 m (overall mean: 3.1 cm) was higher than at 2 m (overall mean: 2.5 cm). The analysis of the rotational flight motion allowed the assessment of the potential threat at several distances from 0.5 to 3.5 m, which was different at each distance, especially regarding the throwing method.

The number of throws needed to hit the target varied statistically significantly between the throwers. Therefore, we calculated the mean values of all throwers to minimize deviations based on the number of throws. For this reason the ratios between all hits per all throws and also all piercings per all throws did not represent equivalent results to the overall mean values of the hit/throw and injury/throw ratios. As expected, the overall mean hit/throw ratio was (statistically significantly) higher at 2 m than at 4 m. The same applied to the injury/throw ratios. Moreover, hitting the target with the paring knife proved to be most difficult, as our results showed. The scissors yielded the highest overall mean hit/throw ratio (recorded at 2 m). However, regarding the hit/throw ratio at 4 m, as well as the injury/throw ratios at both distances, the chef's knife and the skinning knife, namely the heavy objects, yielded the highest overall mean values. In addition, it was shown that the throwing method with the highest overall mean hit/throw not necessarily yielded the highest overall mean injury/throw ratios. The same applied to the scissors at 2 m, which showed the most hits per throw but yielded the lowest overall mean injury/throw ratio. Only at 2 m did the light objects reveal a higher overall mean hit/throw ratio compared to heavy objects. By contrast, the heavy objects demonstrated to be more effective according to the overall mean hit/throw ratio at 4 m and the injury/throw ratios at both distances. The paring knife and the scissors yielded no injury at all for the T/H method, and additionally, the paring knife did not yield an injury for the UA/B at 2 m. Based on the results of this study, using the chef's knife with the UA/B method at 4 m and with the OA/B method at 2 m were the most effective scenarios. The same applied to the injury/hit ratio, thus the most dangerous scenario, at 2 m. At 4 m the most dangerous scenario was demonstrated by the use of the chef's knife with the OA/B throwing method, followed by the UA/B method. The OA/B method yielded the highest overall mean injury/hit ratios at both distances.

For the calculation of the injury/hit, as well as the potential injury/hit values the number of hits was the same for all throwers. The results of the injury/hit ratio revealed the same ranking of the objects at 4 m and at 2 m. The chef's knife and the skinning knife, being the heavy objects, yielded the highest overall mean values compared to the light objects, which was statistically significant at 2 m. Additionally, both heavy knives achieved formidable penetration depths with overall mean maximum values of ≥5.9 cm, a piercing depth that can, if thrown at the abdomen of a lean or even normally built person, lead to serious injuries of the liver, spleen, kidneys or digestive tract. By contrast, the light objects yielded overall mean maximum values of ≤2.7 cm. This on average lesser penetration depth for the scissors and the paring knife is most likely due to the lighter weight and therefore lower potential energy than with the heavier chef's and skinning knife. In general, if thrown from distances of 2 m or 4 m, respectively heavy instruments are more dangerous regarding injuries compared to light objects. The OA/H method caused the highest overall mean depth at 2 m and at 4 m. It can be assumed that holding a knife by the handle may allow for more throw power. An inexperienced thrower may be more cautious holding the blade to avoid self-injury; however, in a real case scenario this restraint will be expected to be suppressed by aggression, which is why the throwers in this study used cut resistant gloves. The overall mean depth of the UA/H method at 2 m is lowered by the paring knife, which did not pierce the abdomen model at all using this throwing method.

The potential injury/hit ratio at 2 m demonstrated the same ranking as the injury/hit ratio at2 m; however, the overall mean values were not equivalent for all objects and all throwing methods. There was a partly less significant difference between the values according to the rankings. The potential injury/hit ratios decrease significantly in accordance with increasing distance from 0.5 to 1.5 m for all objects. As from 1.5 m the differences in the ratios were less pronounced. Only at 0.5 m did the light objects reveal a slight trend to be more dangerous than heavy objects, which can be largely explained by the high injury rate of the scissors thrown at this distance. The scissors revealed high rankings at 0.5 and 1 m; however, thrown from a distance of 1.5 m or further, the scissors were least dangerous. At distances of more than 1 m the heavy objects yielded highest mean injury/hit values. Regarding the throwing methods there were large differences at distances less than 1.5 m. Blade grip throwing methods were far less dangerous at 0.5 and 1 m compared to handle grip throwing methods. Excluding the T/H method, the other throwing techniques caused the objects to move in recurring flight patterns along their trajectory. To be more exact, the knives rotated, thus at every two meters their orientation relative to the target was repeated. Starting at 0.5 m, the sequence of the most dangerous throwing method per distance was as follows: UA/H (0.5 m), OA/H (1 m), UA/B (1.5 m) and OA/B (2 m), repeating as from 2.5 m, thus again, UA/H (2.5 m), OA/H (3 m), UA/B (3.5 m) and OA/B (4 m, according to the injury/hit ranking at 4 m). By contrast, the mean values of the T/H method significantly decreased with increasing distance from the target, starting with the highest mean value at 0.5 m to the lowest at 2 m and so on.

Regarding Muggenthaler et al. [11], who demonstrated that a knife if thrown from 1 m distance and held by the handle can cause injury, it can be assumed that at a throwing distance of 1 m or less a handle-grip throw is more dangerous than a blade-held throw. The most feasible explanation for this is that the blade does not rotate enough to point to the target over such a short distance, a fact which appeared to be true for most of the throwers. The amount of rotation depended mainly on the participants' applied throw power and rotation speed (the latter was not measured in our study). However, our experiments showed that from 1.5 m distance the blade held throws more often resulted in the knife turning the tip towards the target. Furthermore, according to Muggenthaler et al. [11] no injuries were noted if the knives were let slip out of the hand, a style comparable to our T/H throwing method. According to our results, thrust-thrown knives and scissors tended to move with their tips pointing towards the target most often when the flight distance was short. Regarding injury potential, at 2 m the skinning knife even achieved a maximum penetration depth of 6.5 cm using the T/H method. The piercing depth was influenced by the objects weight; although when applying the T/H throw the chef's and the skinning knife could penetrate the target, the paring knife and the scissors failed to do so altogether. Thus, we assumed that from as close as 1 m target distance light objects are very unlikely to cause severe injuries using the T/H method, however, the heavy objects may very well do so.

Regarding the example case mentioned in the introduction, the results of this study suggest that such a scenario would be rather unlikely to happen in the described way, albeit being theoretically possible. Although 84.3% of all throws using the chef's knife hit the target when applying the T/H throwing method, only 13.3% caused an injury. Also 13.3% of all throws caused an injury, as all throwers that caused an injury with the chef's knife using the T/H method had no misthrows. Only three male throwers caused injuries with a mean penetration depth of 2 cm (maximum: 3 cm). The maximum penetration depth for the skinning knife from a distance of 2 m and when applying the T/H method was 6.5 cm. In the example case the chef's knife inflicted an injury of 12 cm depth after it had been randomly hurled at the victim in a thrust-like manner. This stands in contrast to the results of this study, in which deep penetration depths of maximally 9 cm could in fact be achieved by throwing a chef's knife, but only by applying the OA/H method. For this reason, it seems more likely that the woman inflicted the injury by stabbing her boyfriend from a proximate distance rather than by throwing the knife in a T/H method-like fashion, although a penetration injury by throwing the knife using another throw style cannot be fully excluded.

In this study we used four objects representing a realistic spectrum of potentially utilizable throwing instruments; however, we believe that these instruments, being blades used in everyday life, nevertheless represent major groups concerning their proportions and weights. Regarding our synthetic target, despite it lacking hollow organs and thus not being fully comparable to a real human abdomen, we believe that it is a viable model to represent organic skin and soft tissue, namely the structures which – excluding the predominantly dorsally located skeleton - present most resistance to penetration. The utilized ordnance gelatin has proven a viable soft-tissue simulant in numerous ballistic experiments [13–16] and the synthetic skin, too has passed the test of time in other experiments [17–19].

Conclusion

Summarizing the above, the probability of severe injuries due to thrown knives or scissors depends on the weight of the object and the applied throwing method in combination with the distance.

The likelihood of hitting and penetrating a target at 4 m distance is greater if throwing heavier sharp objects, for example the chef's knife and the skinning knife, compared to light ones, such as the paring knife and the scissors. The heavier objects inflicted stab wounds of 6 cm or more depth, whereas the lighter instruments generally penetrated the targets less deep to average depths of less than 3 cm. For short throwing distances, a blade-held throwing technique proved to be less dangerous than the handle-held throwing technique. For example, no penetration of the target was observed using the paring knife with the UA/B technique from a distance of 2 m.

Despite numerous attempts, the thrust-like throwing of the paring knife and the scissors failed to penetrate the target, which is why we deem this method unlikely to cause serious injury when applied with light instruments. However, the heavier instruments, namely the chef's knife and the skinning knife, achieved formidable penetration depths of up to 4 cm using this throwing technique.

The study results give an overview of the potential risk of injury by common knives and scissors that are thrown by applying a variety of techniques. Heavier objects are more dangerous as they yield higher values for the potential injury/throw ratios and penetration depths. Although light objects yielded high (scissors) to moderate (paring knife) results at 0.5 m the penetration depths are expected to be low. At a short distance, the thrust-like throw may lead to injuries, but it is rather unlikely.

Key points

1. Heavier sharp objects are more dangerous when thrown compared to lighter objects, regardless of the throwing distance.
2. For short throwing distances a blade-held throwing technique is less dangerous than a handle-held throw.
3. Depending on the throwing technique heavier instruments are capable of inflicting serious injuries.
4. A thrust-like throwing technique for light objects is very unlikely to harm the target.

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