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The relative effectiveness of two expanding bullet designs in young harp seals (Pagophilus groenlandicus): A randomised controlled field study in the Norwegian harp seal hunt

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Abstract

*The aim of this study was to investigate the relative effectiveness of a rapidly expanding Bonded hunting bullet and an explosively expanding Varmint bullet in young harp seals (*Pagophilus groenlandicus*). The study was conducted as an open, controlled and randomised parallel-group designed field trial. The animals were pre-randomised (1:1) into one explosively expanding (Varmint) and one expanding (Bonded) bullet type group, with 75 animals in each. The study sample consisted of young, weaned harp seals, 2–7 weeks of age, of both sexes, from the Greenland Sea harp seal population. The study was conducted during the regular hunt. Instantaneous death rate (IDR) and time to death (TTD) were the main variables. The observed IDR was 84% in both bullet groups. Correcting for Weather Condition Index, the IDR for the Varmint bullet was significantly higher compared to the Bonded. The mean TTD was shortest in the Varmint group, but the difference did not reach significance. Compared to the Bonded, a significantly higher total cranial damage score and bleeding intensity, and significantly lower frequencies of bullet exit wounds were detected in the Varmint group. The post mortem reflex movements caused by the Varmint bullet were significantly more powerful with longer duration and higher frequencies of clonic contractions. In conclusion, the results indicate a higher effectiveness of the Varmint bullet relative to the Bonded. The Varmint bullet may thus improve animal welfare in the hunt of young harp seals.*

Keywords: *animal welfare, harp seal, hunt, instantaneous death rate, rifle bullet design, time to death*

Introduction

Traditionally, the Greenland Sea or West Ice stock of harp seals (*Pagophilus groenlandicus*) has been important to the Norwegian commercial hunt for ice-breeding seals (Sergeant 1991). Young harp seals are killed, almost exclusively, with a rifle as the primary weapon. The shooting is usually performed from a stand at the bow of the vessel. The killing should be conducted in a three-step process (Anonymous 2003). In the first step, the seal is shot to the head or upper neck, and re-shot if necessary, to cause irreversible unconsciousness and death. To ensure that the animal is dead or remains in a state of unconsciousness until death occurs, the second step requires the shot seal to be approached on the ice as soon as possible and struck through the brain with the spike of the *hakapik* as a secondary weapon. If the animal shows any movements upon approach on the ice, the blow with the spike of the *hakapik* should be preceded by a blow to the calvarium with the blunt part of the tool. In the third step, immediately following the second step, the dead animal is bled out by making an incision along the ventral midline from the lower jaw to the tip of the sternum, followed by severance of the axillary artery on both sides. For animal welfare reasons, rapid induction of unconsciousness and death is important in the first step of the killing process in order to avoid unnecessary pain and suffering (Terlouw *et al* 2016). The power of the rifle and ammunition as well as the properties of the bullet used should be suited for hunting young harp seals.

The prescribed ammunition used on young harp seals was introduced in the early 1990s and extrapolated from those prescribed for hunting smaller terrestrial game animals such as roe deer (*Capreolus capreolus*) and fox (*Vulpes vulpes*). This is soft-point, expanding bullets with an impact energy of minimum 981 J at 100 m, which is calibre .222 and higher (Anonymous 2003; Norwegian Scientific Committee for Food Safety [VKM] 2007).

Soft-point bullets are designed to expand on penetration, changing the projectile into a mushroom-like shape and creating a wide wound canal. This will slow the bullet down and more of its kinetic energy will be transferred to the target area which, in smaller terrestrial game, is usually the thorax (Kneubuehl *et al* 2011). Unlike terrestrial game, seals are shot to the head or upper neck. The skull of young harp seals is thin and softer bullets that expand rapidly with higher energy transfer are preferred rather than deep penetration (North Atlantic Marine Mammal Commission [NAMMCO] 2001; Daoust *et al* 2002).

Recognising that several types of high-velocity, expanding bullet types are commercially available, a NAMMCO expert group meeting recommended further studies on the use of ammunition for hunting seals of different species and age groups, to determine their capacity to achieve the intended effect (NAMMCO 2009).

In recent hunting seasons, some Norwegian seal hunters have used Varmint hunting bullets on young harp seals, claiming their efficiency to be better than that of the conventional soft-point bullets. These bullets are designed for rapid, explosive expansion, and maximum fragmentation.

The damaging effects to the skull from high-velocity expanding soft- or hollow-point bullets of different types and calibres have been proven from shooting tests on the heads of dead young harp seals, adult grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*), and on live grey seals subject to euthanasia (Daoust & Cattet 2004; Øen *et al* 2007; Mörner *et al* 2013). Based on studies under both controlled and field conditions, calibre .17 HMR hollow-point Varmint bullets shot to the head at close range are suggested to be an effective tool to quickly kill young grey seals during a Canadian commercial hunt (Daoust *et al* 2012). To our knowledge, no randomised, controlled field studies have been reported on the relative effectiveness of different expanding rifle bullet designs used for hunting seals.

Time to death (TTD) and instantaneous death rate (IDR) are well established variables to quantify the animal welfare outcomes of cetacean hunting methods (Knudsen 2005; NAMMCO 2015) and, recently, also in the shooting of terrestrial wildlife (Hampton 2017).

The efficacy of the rifle can be influenced by several factors, such as the marksmanship of the hunter, and the conditions under which the hunt is conducted. In the pack-ice hunt, the effectiveness of shooting may be compromised by environmental conditions such as high winds, snowy weather or fog, the bobbing movements of the vessel and of the ice floe upon which the seal is resting, as well as the movements of the animal itself (Daoust & Cattet 2004; European Food Safety Authority [EFSA] 2007). The shooting distance and the number of animals targeted on the ice floe may also be of importance.

The power of the rifle and ammunition used, the properties of the bullet, its design and construction, and ballistics are paramount factors to be considered (Daoust & Cattet 2004; Maiden 2009; Kneubuehl *et al* 2011). The path of the bullet through the air, the exterior ballistics, is affected by wind, gravity and friction (Massaro 2017). Wound ballistics is the study of the bullet's action in tissue (Kazim *et al* 2011; Kneubuehl *et al* 2011). Important elements in determining the wounding capacity of a bullet are its velocity and mass, its shape and design of core and jacket and the ability of expansion, as well as the physical characteristics of the target organ (Maiden 2009; NAMMCO 2009; Kneubuehl *et al* 2011). To kill an animal as quickly and painlessly as possible, as much energy as possible should be transferred from the bullet to the animal. The energy transferred is determined by the instantaneous energy of the bullet and its sectional density (Kneubuehl *et al* 2011).

The conventional soft-point bullets traditionally used in the Norwegian seal hunt, are low cost, lead-tipped bullets that fragment to a certain degree upon impact with the skull of a young harp seal (Fackler 1996). Therefore, to distinguish between the effectiveness of a Varmint bullet designed for rapid explosive expansion and maximum fragmentation and a conventional soft-point hunting bullet, a Bonded expanding bullet, designed for maximum retained weight and penetration, could be used for the latter.

The objective of this study was to investigate the relative effectiveness of an explosively expanding Varmint bullet and a rapidly expanding Bonded hunting bullet in young harp seals.

Materials and methods

The study population consisted of young harp seals belonging to the Greenland Sea harp seal population. A sample of 150, approximately 2–7 week old, weaned harp seals of both sexes were included in the study during a hunt in 2014 (Øritsland & Øien 1995).

The animals were killed as part of a planned hunt which is legal, but strictly regulated in Norway and would have been killed irrespective of whether or not they were subjects in the current study.

Study design and ammunition

The study was conducted as an open, controlled and randomised parallel-group designed field trial during the regular hunt. The animals were pre-randomly allocated (1:1) into two ammunition groups — Varmint and Bonded — with 75 animals in each. In the Varmint group, Winchester Super-X 223 Rem® 55 grain (3.6 g) centrefire jacketed, soft-point bullets with a muzzle velocity of 988 m s^{-1}, a ballistic coefficient of 0.197, and impact energy at 91.44 m of 1,249 J were used (Winchester®, East Alton, Illinois, USA). These bullets are designed for rapid explosive expansion with a soft lead core for maximum fragmentation. In the Bonded group, Winchester Super-X Power Max Bonded 223 Rem® 64 grain (4.1 g) centrefire protected hollow-point bullets with a muzzle velocity of 920 m s^{-1}, a ballistic coefficient of 0.231, and impact energy at 91.44 m of 1,319 J were used. These bullets are designed for rapid expansion with a lead core bonded to the jacket for maximum retained weight and penetration. Due to the bonded core technology, the core remains welded to the jacket after impact. The two bullet types possess approximately the same amounts of kinetic energy and fulfil the impact energy requirements for young harp seals in the Norwegian seal hunt regulations (Anonymous 2003). A Tikka 3® hunting rifle (Sako Limited, Riihimäki, Finland) zeroed at 75 m, equipped with a silencer and a rifle scope, was used throughout the study.

Table 1 Comparison between bullet types regarding factors that possibly could influence instantaneous death rate.

Factor	Category and score	Bullet type		*P*-value
		Bonded	Varmint	
Age group	Beater (1)	20	38	
	Ragged jacket (2)	45	28	< 0.01
	Newly weaned (3)	10	9	
Number of animals on the ice floe	1	55	56	
	2	12	13	0.14
	3	5	2	
	4	0	2	
	5	2	0	
	Missing	1	2	
Behaviour prior to shooting	Unaware (1)	8	6	
	Calm (2)	52	56	0.84
	Anxious (3)	13	10	
	Fear (4)	1	1	
	Missing	1	2	
Number of shots per animal	1	64	61	
	2	10	12	0.65
	3	1	1	
	4	0	1	
Wind category score	Calm (1)	4	0	
	Breeze (2)	22	37	< 0.01
	Fresh breeze (3)	33	14	
	Strong breeze (4)	16	16	
	High wind (5)	0	8	
Weather condition score	Sun (1)	44	25	
	Overcast (2)	17	44	< 0.01
	Snow (3)	14	6	
Visibility score	Good (1)	73	73	
	Reduced (2)	2	2	1.00
Bobbing movements of vessel and ice floes	Minor (1)	26	21	
	Moderate (2)	38	19	< 0.01
	Major (3)	11	35	
Shooting distance (m)	Number of animals	57	65	
	Median	31	36	0.03
	95% Confidence Interval	30–38	33–40	
Weather Condition Index (The sum of wind and weather conditions and bobbing movements of vessel and ice floes)	3	4	0	
	4	12	21	
	5	11	4	
	6	9	12	
	7	20	0	< 0.01
	8	14	16	
	9	5	12	
	10	0	7	
	11	0	3	

Possible influencing factors

Due to similar birth weight and growth rates between harp seal sexes, no differences in bullet performance between sexes were expected (Stewart & Lavigne 1980). However, differences due to age could not be ruled out. Based on the degree of post-weaning shedding of the lanugo fur, the animals were classified into three age groups: two weeks old (newly weaned); 2–4 weeks old ('ragged jackets'); and four weeks or older ('beaters') (Stewart & Lavigne 1980). A significant difference in age was detected between the two bullet groups (Table 1). This difference was used as a correcting factor in the analysis of IDR. The number of animals on the ice floe, animal behaviour prior to shooting, and the number of shots used per animal were observed retrospectively from a video of each animal, see *Study procedure*. No differences were detected between groups regarding these three factors.

The shooting distance was recorded for each animal using binoculars equipped with a range finder (Swarovski EL Range, 8 × 42; Swarovski Optic KG, Absam, Austria) measuring distances exceeding 30 m. The shooting distance was significantly longer in the Varmint group (Table 1). This difference was used as a correcting factor in the analysis of IDR.

Wind and weather conditions, visibility and bobbing movements of the vessel and ice floes were determined subjectively during shooting of each animal. Apart from visibility, the wind and weather conditions, and bobbing movements of the vessel and ice floes, were all significantly better in the Bonded group (Table 1). A Weather Condition Index was created as the sum of scores of these three factors and used as a correcting factor in the analysis of IDR.

Study procedure

Due to possible differences between rifles, all animals were shot with the same weapon. Prior to the hunt, the entire hunting period was divided into consecutive hunting days, defined as days of active hunting. Which bullet to be used on each hunting day was determined randomly prior to the hunt and kept secret to the shooter and researcher until the start of each hunting day. Animals were included in the study in the same order as they were hunted and numbered consecutively. All animals were shot from a stand at the bow of the vessel by the same shooter. Each animal was observed by a veterinarian prior to and during shooting. A video of each animal was made from close to the shooter's stand, starting prior to shooting and ending after the animal was bled.

As soon as possible after shooting, the animal's state of consciousness was clinically assessed by a veterinarian or a trained technician or hunter under veterinary supervision. The following signs of an effective stun/kill were used: immediate collapse; total body relaxation; absence of the corneal and righting reflexes; apnoea; no recovery of rhythmic respiration or any breathing movements of the chest or nostrils; and presence of uncontrolled tonic or clonic spasms, referred to as post mortem reflex movements (EFSA 2007; Daoust & Caraguel 2012). The degree of damage to the skull was investigated visually and via palpation.

Animals assessed as being unconscious or dead after being shot, and re-shot if necessary (step one), were immediately bled (step three), omitting the use of the secondary weapon (step two). Animals showing any voluntary movements of the head, body, flippers or any other sign of consciousness, including paralysis, were immediately stunned with the secondary weapon and bled in line with regulations (Lydersen & Kovacs 1995). No animal was struck-and-lost. On deck, the whole carcase was examined for bullet wounds prior to the head being separated from the body. A post mortem examination of each head was performed shipboard the same day. Skulls with minor damage to the cranium were fixed in 10% neutral buffered formalin and subsequently examined grossly at the Norwegian Veterinary Institute in Tromsø, Norway.

The study was approved by the Norwegian Animal Research Authority under permit number 2014/6264. The described deviations from hunting regulations were legally approved by the Directorate of Fisheries.

Study variables

TTD and IDR were the main variables in the study. TTD was defined as the time (s) from the first shot to hit the animal until irreversible unconsciousness or death occurred. IDR was defined as the proportion of animals for which TTD was zero. The TTD and IDR recordings were made retrospectively from the video of each animal, based on the results from the clinical and post mortem examinations.

The secondary variables were immediate collapse, the degree of body relaxation, post mortem reflex movements (PMRM) variables, bleeding variables, total cranial damage score, and bullet exit wound.

Immediate collapse was defined as immediate loss of posture with no weight-bearing (Verhoeven *et al* 2015). The degree of body relaxation was categorised as 'total relaxation' with no movements of head, body or flippers, as 'gradual relaxation' with an initial tone in front or hind flippers that relaxed gradually within seconds and as 'voluntary movements' with normal mobility or voluntary movements of the head, body or flippers, or paralysis (Lydersen & Kovacs 1995; EFSA 2007).

PMRM, defined as uncontrolled tonic or clonic contractions, are initiated by slight movements of the hind flippers and/or tail, which is the first sign of PMRM, followed by flexion of the caudal portion of the body to one side. This is followed either by clonic contractions, varying in amplitude and characterised by lateral movements of the caudal portion of the body, often referred to as 'swimming reflex' (Daoust & Caraguel 2012), or tonic contractions whereby animals may keep the caudal portion of their body flexed to one side. All time variables were recorded (s). The times to first sign of PMRM and to the first flexion of the caudal portion of the body were recorded from the shot until occurrence of the events. The quality and strength of PMRM were recorded as 'tonic' or 'clonic' contractions, and as weak, moderate or powerful. The duration of PMRM was recorded. The duration of visible external blood flow was defined as the

Table 2 Comparison of instantaneous death rate between bullet types, categorised by impact site and shooting angle.

Factors	Classifications	Bullet type		Total
		Varmint	**Bonded**	
Bullet impact site	Brain and upper spinal cord	100.0 (59/59)	98.2 (54/55)	99.1 (113/114)
		[93.9–100.0]	[90.3–99.9]	[95.2–100.0]
	Cervical vertebrae	0.0 (0/0)	100.0 (5/5)	100.0 (5/5)
		[0.0–0.0]	[47.8–100.0]	[47.8–100.0]
	Head outside cranium or neck outside cervical vertebrae	28.6 (4/14)	33.3 (4/12)	30.8 (8/26)
		[8.4–58.1]	[9.9–65.1]	[14.3–51.8]
	Body	0.0 (0/2)	0.0 (0/3)	0.0 (0/5)
		[0.0–84.1]	[0.0–70.8]	[0.0–52.2]
Shooting angle to the head	0°	71.4 (5/7)	81.8 (9/11)	77.8 (14/18)
		[29.0–96.3]	[48.2–97.7]	[52.4–93.6]
	$0° < x < 90°$	94.9 (37/39)	95.0 (19/20)	96.6 (56/59)
		[82.7–99.4]	[75.1–99.9]	[85.9–98.9]
	90°	71.4 (5/7)	66.7 (16/24)	67.7 (21/31)
		[29.0–96.3]	[44.7–84.4]	[48.6–83.3]
	$90° < x \leq 180°$	72.7 (16/22)	95.0 (19/20)	83.3 (35/42)
		[49.8–89.3]	[75.1–99.9]	[68.6–93.0]
Total		84.0 (63/75)	84.0 (63/75)	84.0 (126/150)
		[73.7–91.5]	[73.7–91.5]	[77.1–89.5]

Results are expressed as percent with 95% confidence interval in square brackets and observed numbers in round brackets.

time from start to end of blood stream ejection from the bullet entrance or exit wound, nose, mouth or other. Bleeding intensity was noted subjectively as scarce, moderate or excessive, based on the amount of blood on the ice, observed external blood flow, and internal bleeding seen as swelling of the head and upper neck. The duration of axillary artery bleeding was defined as the time from cutting the first axillary artery until end of pulsatile ejection of a stream of blood from both arteries (Daoust & Caraguel 2012).

The different cranial bones were grouped into seven anatomical segments: the calvarium (frontal and parietal bones); orbital medial wall (frontal, lacrimal, presphenoid and palatine bones); cranial lateral wall (frontal, parietal, temporal and sphenoid bones); cranial caudal wall (occipital bone); occipital condyle (exoccipital bone); base I (basioccipital, basisphenoid and presphenoid bones); and base II (tympanic and petrosal parts of temporal bone). At post mortem examinations, the damage to each segment produced by the bullet was graded on a scale from 0 to 10, with 0 being no visible gross damage and 10 total bilateral disintegration. The total cranial damage score was the sum of the seven segment scores.

A bullet exit wound was recorded as being either present or absent. Bullet impact site, shooting angle to the head, and the time from shooting to cutting the first axillary artery were used as explanatory variables.

The bullet impact site, defined as the anatomical structures receiving the major damaging effect from the bullet, was categorised into the brain and upper spinal cord (brain and USC), cervical vertebrae and spine only (cervical vertebrae), head outside cranium or neck outside cervical vertebrae (head or neck outside CNS), and body. The head or neck outside central nervous system (CNS) category included hits in maxilla, mandible, orbit, and soft tissue such as skin, blubber and muscle of head or neck, and hits where the bullet had passed through deeper tissue in close vicinity to the cranium or upper cervical vertebrae. The shooting angle to the head was defined as the angle between the direction of the shot and the longitudinal axis of the animal's head: 0° = directly from the front; $0° < x < 90°$ = obliquely from the front; 90°= directly from the side; and $90° < x \leq 180°$ = obliquely or directly from behind.

The time from shooting to cutting the first axillary artery was recorded to provide information relevant for assessing the degree of blood loss prior to exsanguination.

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Table 3 Comparison of instantaneous death between bullet types, categorised by shooting angle within impact site.

Bullet impact site	Shooting angle to the head	Bullet type		Total
		Varmint	Bonded	
Brain and upper spinal cord	0°	100.0 (5/5)	100.0 (6/6)	100.0 (11/11)
		[47.8–100.0]	[54.1–100.0]	[71.5–100.0]
	0° < x < 90°	100.0 (35/35)	100.0 (15/15)	100.0 (50/50)
		[90.0–100.0]	[78.2–100.0]	[92.8–100.0]
	90°	100.0 (5/5)	93.3 (14/15)	95.0 (19/20)
		[47.8–100.0]	[68.1–99.8]	[75.1–99.8]
	90° < x ≤ 180°	100.0 (14/14)	100.0 (19/19)	100.0 (33/33)
		[76.8–100.0]	[82.4–100.0]	[89.4–100.0]
Cervical vertebrae	0°	0.0 (0/0)	100.0 (1/1)	100.0 (1/1)
		[*–*]	[2.5–100.0]	[2.5–100.0]
	0° < x < 90°	0.0 (0/0)	100.0 (4/4)	100.0 (4/4)
		[*–*]	[39.8–100.0]	[39.8–100.0]
Head outside cranium or neck outside cervical vertebrae	0°	0.0 (0/1)	50.0 (2/4)	40.0 (2/5)
		[0.0–97.5]	[6.8–93.2]	[5.3–85.3]
	0° < x < 90°	66.7 (2/3)	100.0 (1/1)	75.0 (3/4)
		[9.4–99.2]	[2.5–100.0]	[19.4–99.4]
	90°	0.0 (0/3)	16.7 (1/6)	19.4 (1/9)
		[0.0–70.8]	[0.4–64.1]	[0.0–48.3]
	90° < x ≤ 180°	28.6 (2/7)	0.0 (0/1)	25.0 (2/8)
		[3.7–71.0]	[0.0–97.5]	[3.2–65.1]

Results are expressed as percent with 95% confidence interval in square brackets and observed numbers in round brackets.
* The confidential interval is not defined

Statistical analysis

Continuously distributed variables are expressed by mean values with 95% confidence interval (CI) calculated using the Student procedure (Altman 1991). Survival Analysis was used for comparison of groups regarding time-to-event variables, and Contingency Table Analysis for categorical or discrete distributed variables (Lee & Wang 2003; Agresti 2013). The IDR is a categorical variable, and the comparison between groups was performed by using the Cochran-Mantel-Haenszel method with Weather Condition Index and age group as correcting factors (Agresti 2013). Additionally, comparison of IDR was performed by using a logistic regression model with shooting distance as covariate (Kleinbaum *et al* 1998).

Time-to-event variables are expressed by Kaplan-Meier plot, and median time to event with 95% CI calculated by the Bernoulli-Wilcoxon procedure (Lee & Wang 2003). Categorical or discrete distributed variables are expressed in contingency tables. Frequencies are expressed in percent with 95% CI constructed using simple binomial sequences (Agresti 2013). All tests were performed two-tailed and differences considered significant for P-values less or equal to 5%. The data analysis was generated using SAS/STAT software for Windows, version 9.4 (SAS Institute Inc, Cary, NC, USA).

Results

The observed IDR was 84% in both bullet groups (Table 2). Correcting for Weather Condition Index, the IDR was significantly higher in the Varmint group (P = 0.02). Although the three factors that were included in the index together had a significant influence on the IDR, the influence was not significant for each factor separately. Correcting for age group and shooting distance did not reveal any significant differences in IDR between groups.

For bullet impacts to the brain and USC, instantaneous death was obtained in all animals, but one in the Bonded group (Table 2). Impacts to cervical vertebrae were only registered in the Bonded group with an IDR of 100%. For impacts to head or neck outside CNS, the IDR was reduced to approximately 30%. No significant difference between groups was

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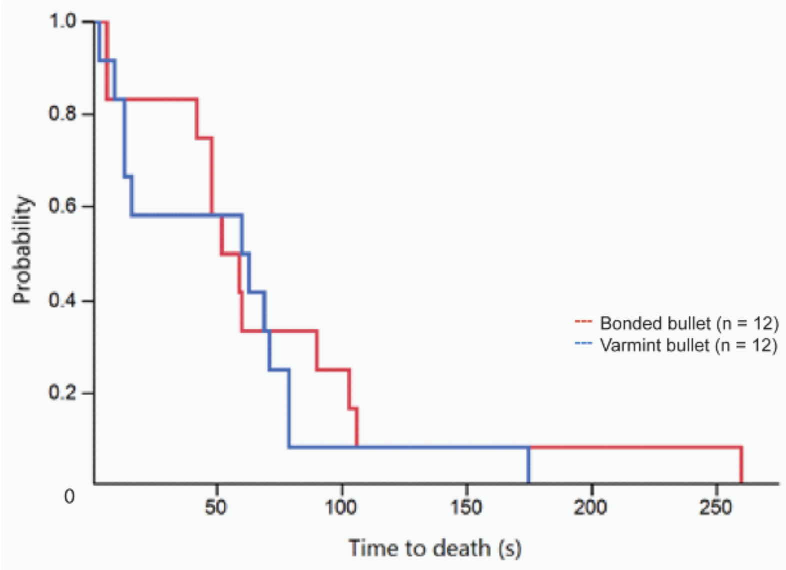
Figure 1



Time to death (s) from shooting to irreversible unconsciousness or death of young harp seals expressed by Kaplan-Meier plot. The red line represents the Bonded bullet and the blue line the Varmint bullet.

detected regarding bullet impact site and IDR. In both groups, the IDR was highest at shooting angles obliquely from the front and obliquely or directly from behind. The lowest IDR was obtained for shots directly from the side. The IDR was significantly higher in the Bonded group at shooting angles obliquely or directly from behind.

The IDR was independent of shooting angle for impact to brain and USC and cervical vertebrae (Table 3). For impacts to the head or neck outside CNS, the IDR was dependent on shooting angle, with the angle obliquely from the front resulting in the highest IDR in both groups. For this impact site, the results indicate an IDR in favour of the Bonded group for all shooting angles, except for angles obliquely or directly from behind.

Twelve animals in each group were not rendered instantaneously irreversibly unconscious or dead. The mean TTD was shortest in the Varmint group with 54 s (95% CI: 19–89) compared to 73 s (95% CI: 38–108) in the Bonded group (Figure 1). Due to the small sample size in this analysis, the difference did not reach the level of significance. In both groups, impacts to head or neck outside CNS were most frequently observed. In total, 18 of the 24 animals were hit in this area, ten in the Varmint group, and eight in the Bonded group (Table 3). All these animals were hit in non-vital structures such as maxilla, mandible, orbit, and soft tissue such as skin, blubber and muscle of head or neck. The mean TTD for this impact area was 22 s longer in the Bonded group, as compared to the Varmint. In both groups, the shortest TTD was recorded for hits to skin and blubber, with a mean of 10 s (n = 4) and 36 s (n = 3) in the Varmint and Bonded group, respectively. The longest TTD was observed for hits to the orbits from an angle directly from the side or wider, with a mean of 111 s (n = 3) in the Varmint group and 260 s for one animal in the Bonded. Five of the ten animals in the Varmint group were shot at angles obliquely or directly from behind. For the other five, three were shot directly from the side, while two were hit directly and obliquely from the front. In the Bonded group, five of the eight animals were shot directly from the side. The remaining three were shot directly from the front or obliquely or directly from behind. Impacts to the body were detected in two and three animals in the Varmint and Bonded group, respectively. In both groups, impacts to the body were all located in the front flipper or scapula. In the Varmint group, the shooting angles to the head were noted as directly from the front and obliquely or directly from behind, while in the Bonded group, as directly from the side in two animals and obliquely from the front in one.

Immediate collapse was observed in 70 and 74 animals in Varmint and Bonded groups, respectively. For the degree of body relaxation, no significant difference was detected between groups. In the Varmint group, 52 animals were classified as 'total relaxation' and eleven as 'gradual relaxation', compared to 56 and seven in the Bonded group, respectively. Twelve animals in each group were classified as 'voluntary movements.'

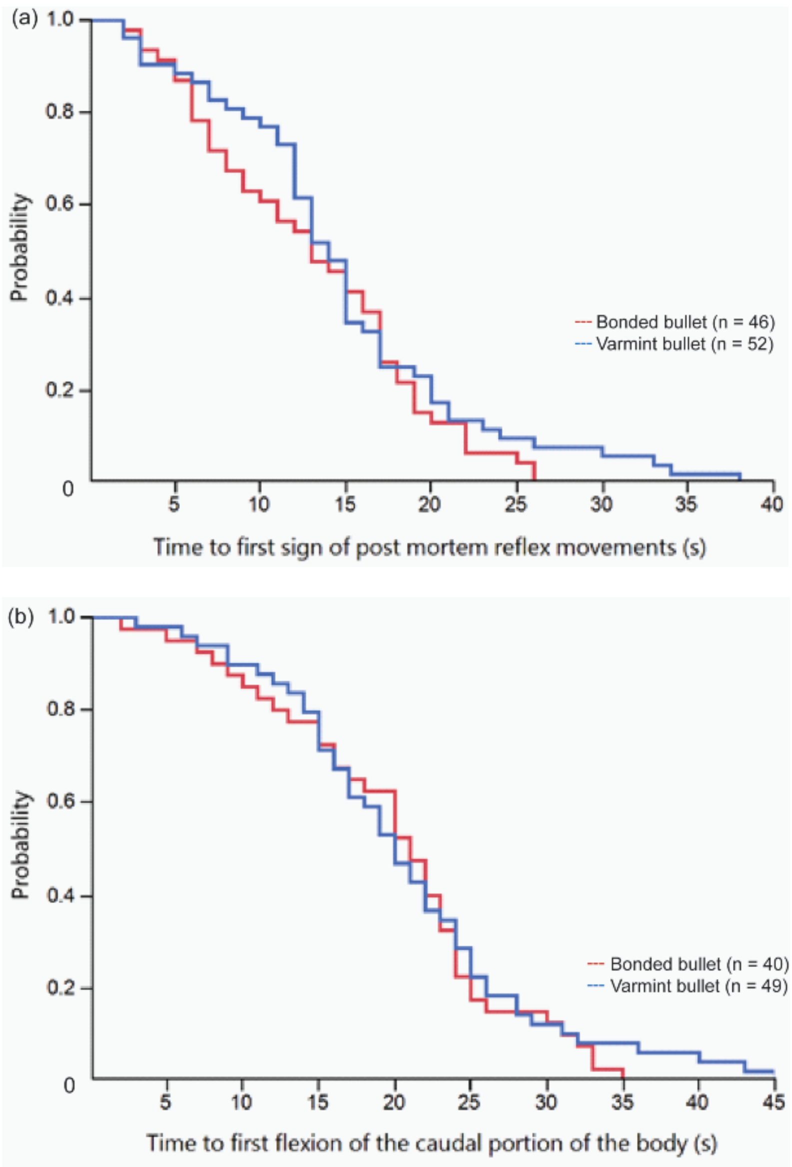
No significant differences were detected between the groups regarding time to first sign of PMRM, and time to first flexion of the caudal portion of body (Table 4, Figure 2[a], [b]). The frequency of 'clonic' contractions was significantly higher ($P < 0.01$) in the Varmint group with 63.2% (95% CI: 51.4–77.8) as compared to 38.8% (95% CI: 25.2–58.1) in the Bonded group. The frequency of powerful contractions was 32.7% (95% CI: 20.7–46.7) in the Varmint

Table 4 Comparison between bullet types regarding time to events and duration of events.

Variables	Bullet type		Total
	Varmint	**Bonded**	
Time to first sign of post mortem reflex movements	14 [12–15]	13 [9–17]	13.5 [12–15]
Time to first flexion of caudal portion of the body	20 [17–22]	21 [17–23]	20.5 [19–22]
Time to cutting first axillary artery	115 [104–130]	105.5 [98–119]	110.0 [102–122]
Duration of post mortem reflex movements	50.5 [44–55]	40 [34–50]	45.5 [39–53]
Duration of external visible blood flow	28 [14–30]	14 [11–22]	20 [14–29]
Duration of axillary artery bleeding	2 [0–3]	2.5 [0–7]	2 [0–3]

Results are expressed as median (s) with 95% confidence interval in square brackets.

Figure 2



Showing time to (a) first sign of post mortem reflex movements, and (b) first flexion of the caudal portion of the body in young harp seals expressed by Kaplan-Meier plot. The red line represents the Bonded bullet and the blue line the Varmint bullet.

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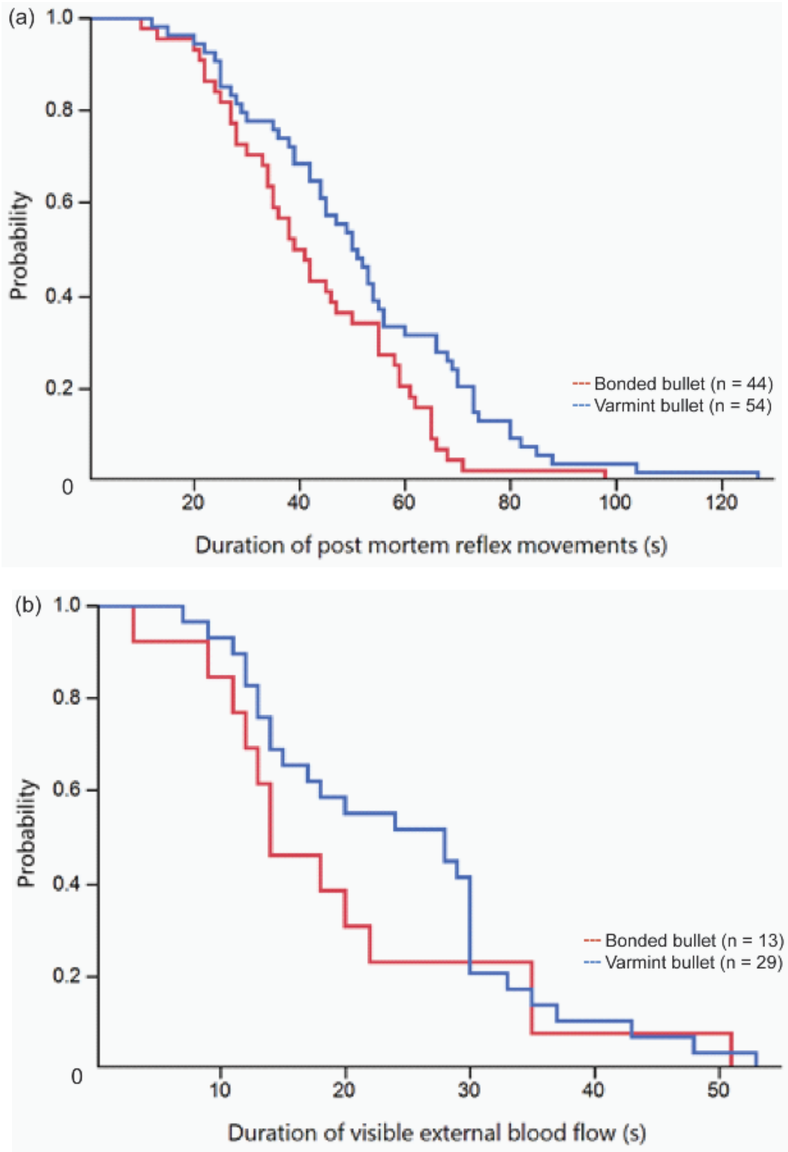
Figure 3



Duration of (a) post mortem reflex movements, and (b) visible external blood flow in young harp seals expressed by Kaplan-Meier plot. The red line represents the Bonded bullet and the blue line the Varmint bullet.

Table 5 Comparison of bleeding intensity and prevalence of a bullet exit wound between bullet types.

Variables	Outcome	Bullet type		Total	*P*-value
		Varmint	Bonded		
Bleeding intensity	Scarce	5	8	13	
	Moderate	7	12	19	0.04
	Excessive	63	55	118	
Bullet exit wound	No	28	12	40	
	Yes	45	60	105	< 0.01
	Inconclusive	2	3	5	
Total		75	75	150	

Results are expressed as observed numbers.

group, compared to 17.0% (95% CI: 7.3–29.7) in the Bonded group. The difference was significant ($P = 0.01$). The duration of PMRM was significantly longer ($P = 0.02$) in the Varmint group (Table 4, Figure 3[a]). The duration of visible external blood flow was longer, and duration of axillary artery bleeding shorter in the Varmint group as compared to the Bonded group (Table 4, Figure 3[b]). These differences were, however, not significant. Time from shooting to cutting the first axillary artery was longer in the Varmint group, but not significantly (Table 4).

The bleeding intensity was significantly higher in the Varmint group ($P = 0.04$) (Table 5). The prevalence of a bullet exit wound was significantly higher ($P < 0.01$) in the Bonded group compared to the Varmint.

The mean total cranial damage score was significantly higher in the Varmint group compared to the Bonded: 48.8 (95% CI: 43.9–53.6) vs 43.0 (95% CI: 38.7–47.3); ($P = 0.04$).

Discussion

The main variables used to quantify the relative effectiveness between bullet types were determined based upon continuous observations of each animal from when it was hit by a bullet until it was confirmed to be irreversibly unconscious or dead. The importance of this continuity of evidence to evaluate the animal welfare outcome of any seal hunt was pointed out by the EFSA (2007).

The recorded IDR was equal for the two bullet types. By coincidence, influencing factors such as wind and weather conditions and bobbing movements of the vessel and ice floes were all found to be unfavourable for the Varmint bullet. However, when correcting for Weather Condition Index, the IDR for the Varmint bullet was significantly higher compared to the Bonded. Hence, the observed IDR proved the Varmint bullet to be as deadly as the Bonded, even in bad weather conditions. When correcting for conditions equal to the Bonded, it appeared to be more effective. This may be explained by the greater wounding potential of the fragmenting Varmint bullet. It has a larger lethal area by making a larger wound than a non-fragmenting one, due to a substantial increase in the size of the permanent wound cavity as each of the multiple fragments spreads out radially from the main wound track and cuts their own path through tissue. This occurs at the same time as the temporary cavity is formed (Maiden 2009).

The IDR observed in the present study is comparable to the IDR detected in young grey seals shot at close range (Daoust *et al* 2012). It is also comparable to the IDRs reported from studies during the hunt of minke whales (*Balaenoptera acutorostrata*) in Norway, fin whales (*Balaenoptera physalus*) in Iceland, and feral dromedary camels (*Camelus dromedarius*) in Australia (Hampton *et al* 2014; NAMMCO 2015). It is above the IDR reported from studies during shooting programmes of European rabbits (*Oryctolagus cuniculus*) and feral horses (*Equus caballus*), but below the IDR reported from culling of peri-urban kangaroos in Australia (Hampton *et al* 2015, 2017; Hampton & Forsyth 2016).

Bullet placement is a critical factor in determining the killing potential of a bullet. Instantaneous death occurs only if the bullet strikes the upper portion of the CNS, comprising the brain and/or upper cervical spinal cord (Maiden 2009).

For impacts to the brain and USC and head or neck outside the CNS, the similar IDRs obtained between groups demonstrated a similar killing efficiency between bullet types. However, for impacts to the brain and USC, a possible difference may have become visible for tangential hits to the calvarium, as exemplified by one animal in the Bonded group not rendered instantaneously dead. The wound was classified as a third degree tangential wound, defined as a wound where the bullet perforates the cranium in the centre of the tangential wound (DiMaio 2016). The bullet had entered the lateral aspects of the frontal calvarium and exited close by through the dorsal aspects of the ipsilateral cranial side wall, before hitting the ice. In this particular tangential hit, much of the kinetic energy of the bullet was probably lost outside the head of the animal. For similar third degree tangential hits to the calvarium, it is reasonable to assume that the Varmint bullet may kill more efficiently due to its greater wounding potential through fragmentation, and greater energy transfer in its passage through the cranial wall as compared to the Bonded (Kneubuehl *et al* 2011; DiMaio 2016).

For impacts to head or neck outside the CNS, the IDR in both groups was entirely represented by hits where the bullet had passed through deeper tissue in close vicinity to the cranium or upper cervical vertebrae. In most cases, the bullet had passed close to the base of the skull, producing gross subdural and subarachnoid haemorrhages, often massive, particularly on the ventral surfaces of the brainstem. Vascular injuries in these sensitive and vital parts of the brain have been documented as correlating significantly with mortality (Knudsen & Øen 2003; Øen & Knudsen 2007; Kazim *et al* 2011; Kneubuehl *et al* 2011). Similar instantaneously fatal effects from high-velocity bullet impact outside the cranial cavity have been reported in minke whales (Øen & Knudsen 2007).

The shooting angle to the head appeared to be an important explanatory variable to the IDR. For both bullet types, the highest IDR was detected for the angles obliquely from the front and obliquely or directly from behind. The fact that the bullet must pass through or close to the brain or upper spinal cord when shot from these angles, may explain these findings. The deeper penetration properties of the Bonded bullet compared to the Varmint, might be responsible for the significantly higher IDR detected for this bullet at angles obliquely or directly from behind (Kneubuehl *et al* 2011). From these angles, the head may be partly or entirely hidden in front of the body if the animal's head is down. If fired in such situations, the bullet may have to penetrate additional tissue in the thoracic back before reaching the head/upper neck. The IDR was lowest for both bullet types at a shooting angle directly from the side. Unlike shots from the angles discussed above, the bullet may not necessarily strike the upper CNS, but non-vital structures such as the maxilla or mandible, when hitting the head directly from the side.

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For impacts to the brain and USC and cervical vertebrae, the IDR was independent of shooting angle. At least for hits to the brain and USC, this demonstrates the ability of both bullet types to produce instantaneous fatal injury to the upper CNS from any angle to the head. However, a dependency between IDR and shooting angle was detected for impacts to the head or neck outside CNS. For both bullet types, the angle obliquely from the front resulted in the highest IDR. The sample size in each shooting angle category was too small to conclude any difference between bullet types regarding shooting angle and IDR within this impact site.

Twelve animals in each group were not rendered instantaneously dead or irreversibly unconscious. Although not significant, the mean TTD was 19 s shorter in the Varmint group as compared to the Bonded. One of these animals was hit in the brain and USC as previously described, 18 in the head or neck outside CNS, and five in the body.

For impacts to the head or neck outside CNS, all the animals were hit in non-vital structures such as maxilla, mandible, orbit, and soft tissue like skin, blubber and muscle of the head or neck. Animals that are hit in the skin and blubber, show immediate or early signs of consciousness and are rapidly re-shot. The recorded TTD becomes shorter. This was particularly evident in the Varmint group. The longest TTD was observed for hits to the orbits from an angle directly from the side or wider. This was particularly evident in the Bonded group. Impacts to the orbits from such angles implies damage to deeper structures near the brain, which may prolong the time until signs of voluntary movements are evident. Hence, the recorded TTD becomes longer.

No difference between groups was detected regarding immediate collapse, which is an indicator of the potential loss of consciousness (American Veterinary Medical Association [AVMA] 2013; Terlouw *et al* 2016). It was observed in all animals apart from one in the Bonded and four in the Varmint group, demonstrating that the transfer of kinetic energy from both bullet types was sufficient to induce loss of consciousness even in animals that survived the first shot (Kneubuehl *et al* 2011; Finnie 2016).

The two bullet types also performed similarly regarding the degree of body relaxation. Total body relaxation is associated with complete destruction of the brain and brain-stem (EFSA 2007) and was mostly represented by cases with severe primary brain damage. Animals with 'gradual relaxation' had less destructive but lethal primary brain damage (Finnie 2016), while 'voluntary movements' as a sign of consciousness was entirely represented by the 12 animals in each group not rendered instantaneously irreversibly unconscious or dead.

The occurrence of PMRM indicates effective mechanical stunning in slaughtered livestock (Verhoeven *et al* 2015). In seals, they are indicative of a successful killing, as verified in the present and other studies (Daoust *et al* 2002; Daoust & Caraguel 2012). The PMRM likely result from the loss of higher motor control following acute trauma to the head or neck (Daoust & Caraguel 2012; Verhoeven *et al* 2015). The onset of PMRM, as documented by the times to first sign of PMRM and to first flexion of the caudal portion of the body, was similar between the bullet types. Hence, provided fatal damage to the upper CNS has occurred, the timing of the mechanisms initiating these reflex movements seems to be the same, regardless of damage produced by the different bullet types. However, the frequencies of 'clonic' as well as powerful contractions were significantly higher, and the duration of PMRM significantly longer in the Varmint group as compared to the Bonded. The substantially larger damaging effect to the brain caused by the Varmint bullet, as evidenced by the higher total cranial damage score, might explain these observed differences. The more pronounced and thus more visible PMRM produced by the Varmint bullet make it easier for the shooter to assess the effect of the shot.

The significantly higher bleeding intensity detected in the Varmint group, indicates a higher rate of blood loss in this group immediately after shooting. The most excessive bleeding was observed as both external and internal bleeding, where the latter appeared as swelling of the head and upper neck region, developing within seconds of impact. This phenomenon was more frequent and pronounced in the Varmint group. In both groups, swelling was mainly associated with total disintegration of cranium and brain architecture. It seems likely that the swelling was caused by the pumping of arterial blood from disrupted arteries into the large permanent wound cavity of the head covered by the skin. The rate of blood loss is determined by the size of the bullet wound through the relevant blood vessels, as well as the pressure in the vessel at that time (Maiden 2009). In general, the larger wounding capacity of the Varmint bullet, due to the maximum deformation and maximum amount of temporary cavitation, would crush more tissue and disrupt more arteries in the head and upper neck region (Maiden 2009).

The short duration of axillary artery bleeding in both groups was indicative of a substantial blood loss prior to exsanguination, which could be explained by the relatively long time from shooting to cutting the first axillary artery. The observed duration of axillary artery bleeding was comparable to that seen in young harp seals shot with similar ammunition in the Canadian harp seal hunt, taking into consideration that different end-points were used (Daoust & Caraguel 2012).

The significantly lower prevalence of a bullet exit wound in the Varmint group proved that the entire bullet energy was used inside the skull in a larger proportion of cases, resulting in a rapid kill (Kneubuehl *et al* 2011). Consequently, the risk of accidental injuries to neighbouring seals caused by perforating shots is reduced (Øen *et al* 2007).

Animal welfare implications and conclusion

The detected differences in IDR and TTD indicate a higher effectiveness of the Varmint bullet relative to the Bonded. This was supported by the higher total cranial damage score and bleeding intensity produced by the Varmint bullet. Together with the more pronounced and thus more visible PMRM and the lower frequency of bullet exit wounds, these findings strongly indicate that the Varmint bullet may improve animal welfare in the hunt of young harp seals.

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