Eur J Wildl Res
DOI 10.1007/s10344-016-1006-0

ORIGINAL ARTICLE

Efficacy of non-lead rifle ammunition for hunting in Denmark

Niels Kanstrup[1] · Thorsten J. S. Balsby[2] · Vernon G. Thomas[3]

Received: 18 January 2016 / Revised: 18 March 2016 / Accepted: 28 March 2016

Abstract Lead has traditionally been used for making hunting ammunition. However, lead from spent hunting bullets has proven to be a health hazard for wildlife, ecosystems, and humans. The transition to use non-lead ammunition for hunting raises several concerns, especially *inter alia* the question of efficacy. This study examined whether non-lead rifle ammunition fulfills the demands of ethical and humane hunting by causing a rapid kill of hunted animals equivalent to lead rifle ammunition. A field sample of 657 hoofed animals, most red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*), were hunted under normal Danish conditions by sport hunters using commonly used rifle calibers. The efficiency of copper versus lead bullets was tested using flight distance after being hit as the primary response parameter. For red deer, we were not able to show any statistical significant difference between performance of non-lead and lead bullet. For roe deer, we found a small, statistically significant, relation between flight distances and shooting distance for roe deer struck with non-lead bullets but not with lead bullets. However, this difference was not of such magnitude as to have any practical significance under hunting conditions. We conclude that in terms of lethality and animal welfare, non-lead ammunition within the tested range of bullet calibers can be recommended as an effective alternative to lead-core bullets.

Keywords Hunting · Lead-free · Copper · Bullets · Efficacy · Roe deer · Red deer

Introduction

Since the invention of firearms, lead has been the preferred material for ammunition because lead is relatively cheap, is easy to extract, and make into bullets. Lead has a high density, enabling bullets to retain their kinetic energy, and has good ballistic properties because its softness confers a great ability to deform and expand inside the target. However, the development of non-lead products during the last two to three decades has shown that other materials can substitute for rifle bullets (Thomas 2013; Kanstrup 2015; Gremse et al. 2014). Furthermore, lead is a toxic heavy metal, and there is increasing concern about the risk of poisoning of scavengers that eat animals and their remains after being shot or wounded with lead ammunition (Watson et al. 2009; Haig et al. 2014; Nadjafzadeh et al. 2013; Golden et al. 2016). There is also a growing concern about the health risk to people who frequently eat game shot with lead bullets and being exposed to lead levels above recommended values (Knott et al. 2010; Pain et al. 2010; Bellinger et al. 2013; Knutsen et al. 2015).

Various types of non-lead rifle bullets are produced and marketed, copper and copper-zinc alloys being the most

Electronic supplementary material The online version of this article (doi:10.1007/s10344-016-1006-0) contains supplementary material, which is available to authorized users.

✉ Niels Kanstrup
nk@danskjagtakademi.dk

Thorsten J. S. Balsby
thba@bios.au.dk

Vernon G. Thomas
vthomas@uoguelph.ca

1 Danish Academy of Hunting, Skrejrupvej 31, 8410 Rønde, Denmark

2 Department of Bioscience, Aarhus University, Grenåvej 14, Building 8411, 8410 Rønde, Denmark

3 Department of Integrative Biology, University of Guelph, Guelph, Ontario N1G 2W1, Canada

Published online: 07 April 2016

widely used alternatives (Thomas 2013; Kanstrup 2015). Introduction of non-lead hunting ammunition raises a number of issues including efficacy, toxicity, safety, availability, and price (Knott et al. 2009, 2010; Thomas 2015a, b). The efficacy of lead-free rifle bullets to produce rapid fatality has been demonstrated under controlled experimental situations (Grund et al. 2010) and when using ballistic soap to simulate animal tissue (Gremse et al. 2014). Trinogga et al. (2013) used a structural analysis of wound channels of hunted animals to compare the ballistic performance of lead-free and lead-core bullets to conclude that their killing efficacy was likely similar. However, it is the ability of sport hunters to use lead-free rifle bullets with confidence against an array of species that will influence their adoption of these lead-core substitutes, and ultimately, their acceptance of any government regulation requiring their use (Cromie et al. 2010). Thus, it is important to assess the efficacy of such lead-free bullets when used by conventional sport hunters under field hunting situations, in which uncontrolled conditions may apply. Knott et al. (2009) conducted such a preliminary field study in the UK on British deer which supported the use of non-lead bullets. Spicher (2008) reported that 95 % of 247 animals in Germany (mainly deer and wild boar (*Sus scrofa*)) were killed rapidly by a single shot made from non-lead material. The present study is the first large-scale test of the efficacy of non-lead, copper, rifle bullets' ability to safely and humanely kill hunted wild game animals with that of equivalent lead-core bullets when used by sport hunters. We compared the flight distance of animals struck by copper and lead bullets, while taking the shooting distance and bullet terminal strike energy into account in the analyses. The null hypothesis tested was that there is no difference in flight distance for animals shot with lead-core bullets compared to animals shot with copper bullets.

Methods

Sampling methodology

During three hunting seasons (years 2012–2014), 15 licensed and experienced Danish hunters collected data from 657 animals killed under customary hunting situations. Hunters were free to select the bullet caliber, bullet weight, and type consistent with accuracy from their rifles. Each rifle was sighted in to achieve accurate placement of bullets within shooting distances normal for that type of hunting. All hunters knew which type of bullet they fired (i.e., copper or lead-core) when each animal was killed. Ninety percent (591) of the data were taken from animals hunted in Denmark while the remaining 10 % (66) were taken in Sweden, Ireland, and Germany. Sixty-six percent (307) of the sample was red deer (*Cervus elaphus*), and 34 % (161) roe deer (*Capreolus capreolus*). For the analyses in this paper, we only used the observations with frequently used calibers on red deer (224) and roe deer (133), which reduced the sample size to 357 observations.

The data were obtained from animals shot with commonly used firearms and cartridge calibers. The most common calibers used were 30-06, .308 WIN, 6.5×55, and .270 WIN (a total of 75 % of the sample), with the remaining being small calibers such as .222 REM and .223 REM, and large calibers, e.g., 9.3×62. Distribution of calibers used to hunt red and roe deer is shown in Fig. 1. Thirty percent of the overall sample were taken with lead bullets, 70 % with copper bullets. Twenty-five percent ($n = 33$) of the roe deer were taken with lead bullets and 75 % ($n = 100$) with copper bullet. The corresponding numbers for the red deer sample were 40 % ($n = 91$) and 60 % ($n = 133$). Hunters recorded for each animal shot the shooting distance, the animal's flight distance (the distance traveled by the shot animal before falling dead), movement of the animal at the time of shooting (standing, walking, running), location of the bullet's entry, bullet caliber, brand of ammunition, hunting area location, and date. Shooting and flight distances were estimated by each hunter

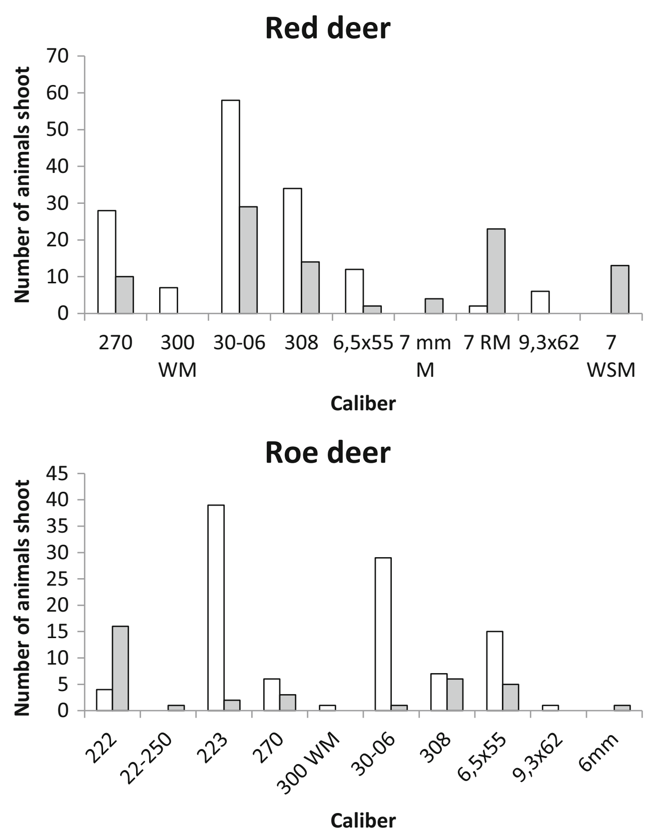

Fig. 1 Number of animals shot with different rifle calibers and bullet material. *White columns* represent copper bullets and *gray columns* represent lead-core bullets. The rare calibers, omitted in the later analyses, were included in this figure. Red deer ($N = 242$) and roe deer ($N = 137$)

either by eyesight, counting of measured steps, or use of electronic range finders. An estimate of the strike energy of the bullet was made based on the shooting distance, the mass, and muzzle velocity of the bullet as specified by the bullet's manufacturer. The estimate of strike energy assumed that the velocity of the bullet declined with 1 m/s per 1 m shooting distance, based on ballistic data given by a variety of rifle cartridge manufacturers. This calculation assumes that the correlation was linear within the range of shooting distances that were registered in this study. Shooting distances ranged from 7 to 380 m, with 80 % less than 100 m. Flight distances ranged from 0 to 1500 m, with 90 % <100 m (Fig. 2).

Data analysis

The efficacy of the non-lead ammunition was tested in comparison with lead ammunition using flight distance as the criterion. To account for the variation in size of the animals in addition to the difference among bullet calibers, shooting distance, and flight distance, we analyzed data for red deer and roe deer in separate tests. We included only "one shot kills" of red and roe deer in the analyses because this is the best test of a single bullet's efficacy in producing a rapid death.

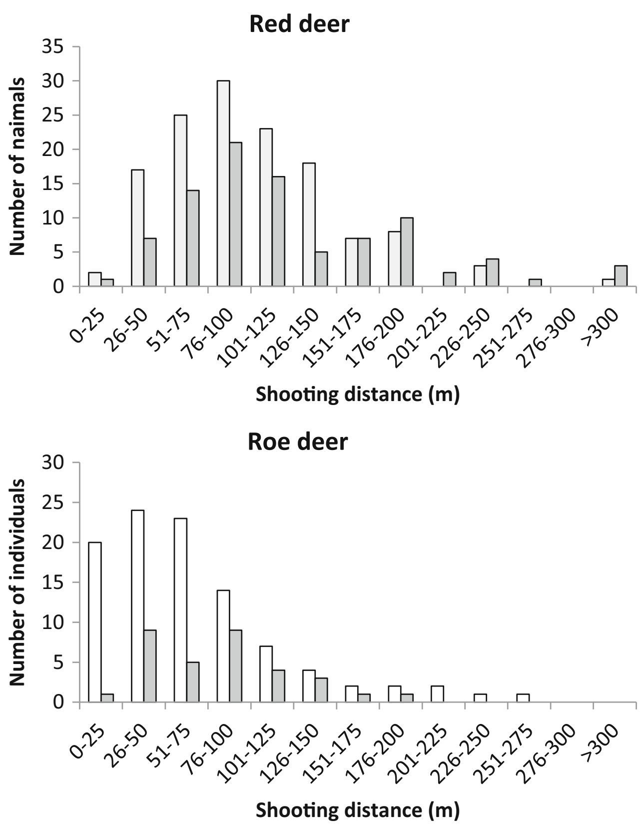

Fig. 2 Number of red deer and roe deer shot at different shooting distance classes by copper bullets (*white columns*) and lead-core bullets (*gray columns*). Note that the statistics were made on the continuous shooting distance

Calibers which had been used less than 9 times for shooting roe deer and less than 13 for shooting red deer were omitted to enhance the robustness of the analyses. Hence, the calibers used in the calculations for roe deer were .222 REM, .223 REM, .270 WIN, 30-06, .308 WIN, and 6.5×55. Calibers used for red deer were .270 WIN, 7 MM RM, 7 MM WSM, 30-06, .308 WIN, and 6.5×55 (see supplementary material Table S1). The majority of the shots were shots placed in the heart and lung region. Data for a few shots placed in the abdomen were omitted from the analyses.

We used general linear mixed models and generalized linear mixed models (Littell et al. 2006) to test the influence of type of bullet material, movement of the animal at the time of shooting, strike energy, and shooting distance on flight distance. Due to collinearity issues, shooting distance and strike energy had to be tested in separate models. In the mixed model, we included covariates such as shooting distance or strike energy to reduce the effect of confounding variables in the dataset. To test the effect of bullet material (i.e., lead-core versus copper bullet), we included shooting distance, movement of the animal, and the interactions between shooting distance or strike energy and bullet material, and between movement of the animal and bullet material in the model. We used caliber as random effects as all shots taken with the same caliber would be expected to be more similar than shots made with other calibers, and hence the observations would not be equally independent. Each hunter has contributed multiple data points for the same species. These were considered independent observations as shooting distance and flight distance were rigorous measures that do not differ systematically between hunters, and the only factor that differed systematically was caliber, which was incorporated as a random factor. To illustrate the significant interaction effects, we used linear regressions. In all statistical tests assuming normal distribution, we tested for normality and homoscedasticity by examining probability plots and plots of residuals versus predicted values. The residuals for each test did not deviate from assumptions regarding normality and homoscedasticity. We used SAS ver 9.3 (SAS Institute, Cary, NC) to conduct all statistical analyses using proc mixed, proc glimmix, and proc glm. Statistical significance was accepted at $p \leq 0.05$.

Results

The original data set consisted of 137 roe deer and 242 red deer. However, after omitting data for the rarer calibers, the set consisted of 133 roe deer, of which 100 were shot with copper bullets and 33 shot with lead-core bullets, and 224 red deer, of which 133 were shot with copper bullets and 91 were shot with lead-core bullets. For these data, several parameters differed between roe and red deer. The use of calibers has limited overlap (Fig. 1). For red deer, shooting distances were significantly larger than for roe deer (Fig. 2, Mixed model $F_{1,365}=10.97$, $p=0.001$). Likewise, flight distances for red deer were significantly longer for red deer than for roe deer (Fig. 3, generalized linear model assuming Poisson distribution $F_{1,364}=195.6$, $p<0.001$), and longer flight distances occurred more frequently for red deer than for roe deer. Due to these differences between roe deer and red deer, the two species data sets were analyzed separately (Fig. 4).

Shooting distances did not differ between copper bullets and lead-core for roe deer (General linear model $F_{1,131}=2.06$, $p=0.151$). For red deer, the shooting distance was significantly larger with lead-core bullets (125 m) than for copper bullets (105 m) (General linear model $F_{1,223}=5.87$, $p=0.016$).

Effect of bullet material and shooting distance on the flight distance

The bullet material did not have an effect on the flight distance, although there was a statistically insignificant tendency for roe deer to show longer flight distances when shot with lead bullets compared to copper bullets (Table 1). However, the bullet material may have importance, as both the interaction effect between bullet material and shooting distance, and the interaction between bullet material and animal movement showed significant effects on flight distance for roe deer (Table 1).

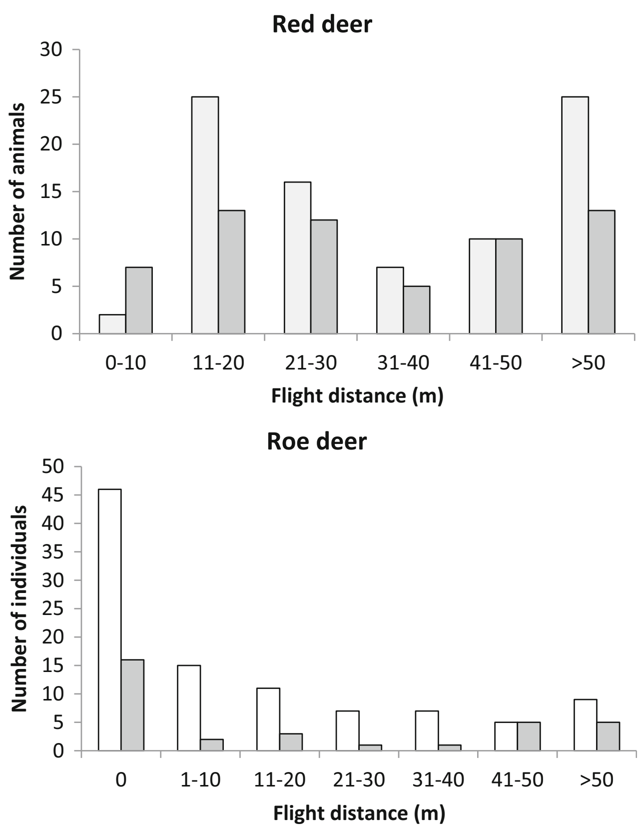

Fig. 3 Numbers of red deer and roe deer for each flight class distance shot with copper bullets (*white columns*) and lead-core bullets (*gray columns*). Note that the statistics were made on the continuous distance

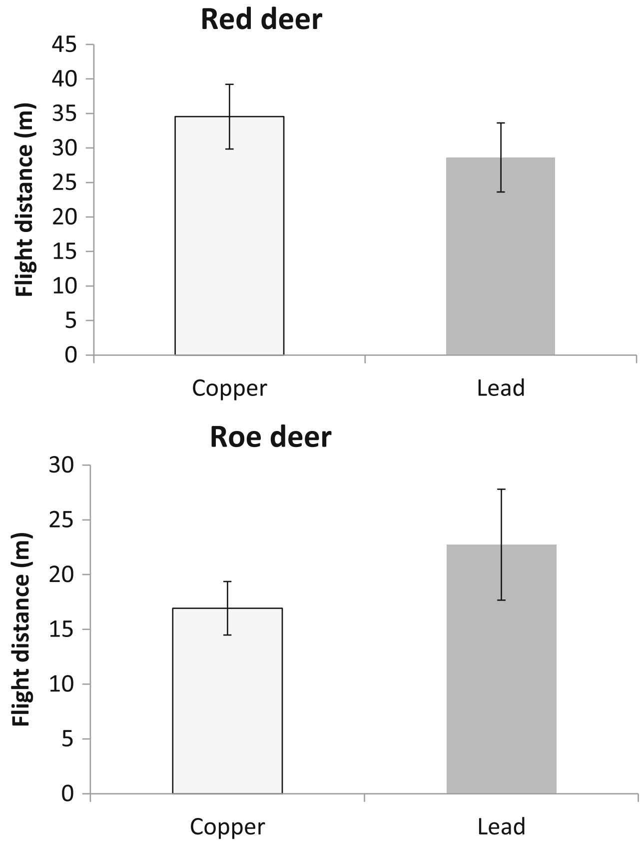

Fig. 4 Flight distance (mean ± SE) for red deer and roe deer shot with either lead-core (*gray*) or copper (*white*) bullets. Only the frequently used calibers were used for this estimate

The interaction effect between animal movement and bullet material was significant for roe deer. The pair wise comparison showed that flight distance was significantly larger for animals that were standing compared to animals that were walking when they were shot (least square means difference $t_{96}=2.50$, $p=0.014$). The pair wise comparison relating to bullet material was not significant, but indicated a larger flight distance for copper compared to lead-core bullets for both walking and standing roe deer (least square means difference, standing $t_{96}=1.68$, $p=0.097$; walking $t_{96}=1.81$, $p=0.073$). The significant interaction between shooting distance and bullet material suggests that the effect of shooting distance relative to flight distance differs between bullet materials. To illustrate these relations for each material, we tested the relation between shooting distance and flight distance for lead-core and copper bullets separately. The flight distance for roe deer shot with copper bullets increased significantly with increasing shooting distance, whereas the

Table 1 Test for effect of bullet material, movement of the animal at the time of shooting, and shooting distance on the flight distance of roe deer and red deer. The data were analyzed using a mixed model with caliber as a random effect

	Red deer			Roe deer		
	df	*F*	*p*	*df*	*F*	*p*
Shooting distance	1, 209	1.34	0.249	1, 96	1.94	0.167
Material	1, 209	1.67	0.198	1, 96	3.33	0.071
Movement	2, 209	0.27	0.760	2, 96	2.07	0.132
Material × movement	2, 209	0.89	0.413	1, 96	5.49	0.021
Shooting distance × material	1, 209	0.02	0.890	1, 96	9.38	0.003

relation between flight distance and shooting distance was not significant for lead-core bullets (Fig. 5, General linear model, copper bullet: $R^2=0.048$, $F_{1,98}=4.89$, $p=0.029$, slope = 0.102; lead-core bullet: $R^2=0.063$, $F_{1,31}=2.10$, $p=0.158$, slope = −0.164). For red deer, there were no significant effects of bullet material, movement of the animal, shooting distance, and their interaction effects (Table 1, Fig. 6). Copper bullets, however, tended to result in longer, but statistically insignificant, flight distances than lead-core bullets (Fig. 4). Flight distances for red deer tended to increase with shooting distance, but this relation was not significant (Table 1).

Effect of terminal strike energy and bullet material on flight distance

Bullet material did not have any effect on flight distance when combined with strike energy within the tested range of strike energy (approximately 2500 to 5000 J). Neither strike energy, bullet material, nor the interaction between them showed significant effects on the flight distance for roe deer and red deer (Table 2). There was no significant relation between flight distance and impact energy for either lead-core or copper bullets for roe deer and red deer (Table 2).

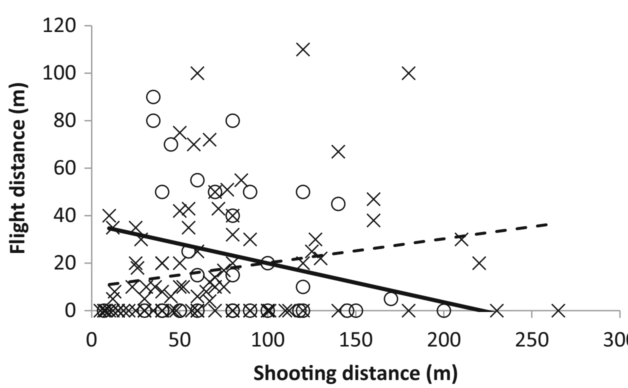

Fig. 5 Relation between shooting distance and flight distance for roe deer shot with lead (*circles*) and copper (*crosses*) bullets. The *lines* represent the regression for the relationships: *broken line* denotes copper bullets, and *solid line* for lead-core bullets. Regression for copper bullets: $R^2=0.05$, slope = 0.102, $t_{98}=2.21$, $p=0.029$, intercept = 9.98, $t=2.53$, $p=0.013$. Regression for lead-core bullets, $R^2=0.06$ slope = −0.164, $t_{31}=1.45$, $p=0.158$, intercept = 36.3, $t=3.42$, $p=0.002$

Discussion

The results of this realistic comparison using actual hunters under prevailing hunting conditions affirms the efficacy of copper bullets in producing rapid incapacitation, of red and roe deer. The result is consistent across a range of practicing recreational hunters and a range of different bullet brands, calibers, and bullet types. The flight distances observed for both deer species struck by copper bullets was largely less than 50 m, reflective of rapid death and assured retrieval of the shot animal. This field comparison of the two bullet types indicates that a transition to non-lead rifle ammunition can be undertaken with no adverse consequences to the hunters and hunted given the array of non-lead ammunition already available. Two field comparisons, one in the UK Knott et al. (2009), and the present Danish study, endorse the practicality of this transition.

What constitutes an effective and humane kill in a hunting context is not defined in Danish hunting regulations, but it is

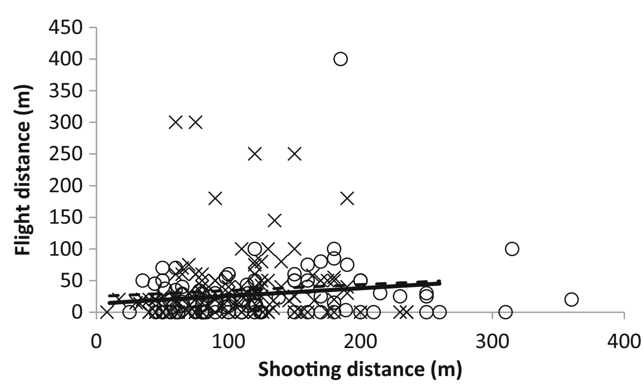

Fig. 6 Relation between shooting distance and flight distance for red deer shot with lead (*circles*) and copper (*crosses*) bullets. The *lines* represent the regression for the relationships. Regression for copper: $R^2=0.006$, slope = 0.09, $t_{131}=0.92$, $p=0.360$, intercept = 24.9, $t=2.15$, $p=0.033$. Regression lead: $R^2=0.030$, slope = 0.122, $t_{89}=1.66$, $p=0.101$, intercept = 13.4, $t=1.29$, $p=0.202$

Table 2 Test for effect of strike energy and material on flight distance for roe deer and red deer. The data were analyzed with a mixed model with caliber as a random effect

	Red deer			Roe deer		
	df	*F*	*p*	*df*	*F*	*p*
Strike energy	1, 201	1.71	0.193	1, 96	0.01	0.941
Material	1, 201	0.33	0.564	1, 96	3.89	0.052
Movement	2, 201	0.53	0.589	2, 96	0.61	0.544
Material × movement	2, 201	1.07	0.345	1, 96	3.08	0.083
Strike energy × material	1, 201	0.85	0.357	1, 96	2.49	0.118

implicit that the demands of animal welfare require killing the quarry as rapidly as possible and avoiding prolonged suffering (Aebischer et al. 2014). Given this consideration, we regard the flight distance to be a valid criterion, as flight distance in most cases will reflect the time from the animal is hit until it dies ("time do death"). Furthermore, flight distance is a variable that is relatively easy to measure.

The flight distance is dependent on major variables such as body size of the animal, hitting point, shooting distance, rifle caliber, bullet mass and velocity, and bullet type and construction. The question is whether this dependence is more or less pronounced for non-lead ammunition compared with lead-core ammunition (Caudell et al. 2012). The expansion and fragmentation of bullets is regarded as a fundamental property to ensure that the bullet delivers its energy and creates sufficient injury to vital sections of the body to cause rapid death (Caudell 2013). Therefore, lead-core bullets are traditionally designed to expand and fragment, whereas lead-core bullets designed not to expand (e.g., full metal jacket bullets) are not allowed for hunting. Non-lead bullets fragment much less than lead-core bullets (Grund et al. 2010; Cruz-Martinez et al. 2015). However, non-lead bullets are designed to either expand (most types) or fragment into a few sections thus creating adjacent tissue injury in addition to the injury caused by the bullet in the prime wound channel. A typical expanding copper bullet will, on entering the animal, double its diameter and achieve a mushroom shape (Fig. 7, right), and despite that almost no bullet mass is lost as fragments, will have a dramatic physiological impact provided that the expansion is released in a depth that ensure injury to vital organs.

In our comparison of lead versus copper bullets, there was a tendency for copper bullets to result in longer flight distances for red deer. However, the trend did not show statistical significance. For roe deer, we found a statistically significant increase of flight distance with shooting distance for copper bullets, but not for lead bullets. In addition, we found that the main factor for material differed significantly between non-lead and lead bullets. This difference was not related to precision of bullet strike, choice of caliber, or other variables. However, the difference between copper and lead-core bullets become important only at shooting distances beyond 100 m, at which flight distances for roe deer shot with copper bullets become larger than those shot with lead-core bullets. Because shooting distances above 100 m are rarely seen in a practical Danish hunting context, this finding does not disqualify the use of copper bullets. Also for red deer, we found an overall statistical significant correlation between flight distance and shooting distance, but with no difference between lead-core and copper bullets.

In the present study, lead-core and copper bullets did not differ in efficacy when accounting for shooting distance and strike energy for red deer. For roe deer, the flight distance increased with shooting distance for copper but not for lead-core bullets. One reason for this could be the lower strike energy in the smaller bullets used for roe deer hunting. However, neither strike energy nor the interaction between strike energy and bullet materials had a significant effect on flight distance for roe deer. The energy in the bullet therefore seems an unlikely explanation for the positive relation between shooting distance and flight distance. It is more likely that the ballistic behavior of the bullet upon impact changes with the strike velocity, which especially for small copper bullets declines faster with increasing shooting distance. It is well known that lead bullets have a larger propensity to fragment upon hitting the animal compared to copper bullets (Caudell et al. 2012; Grund et al. 2010; Thomas 2015a). This could explain the observed difference in flight distance, which

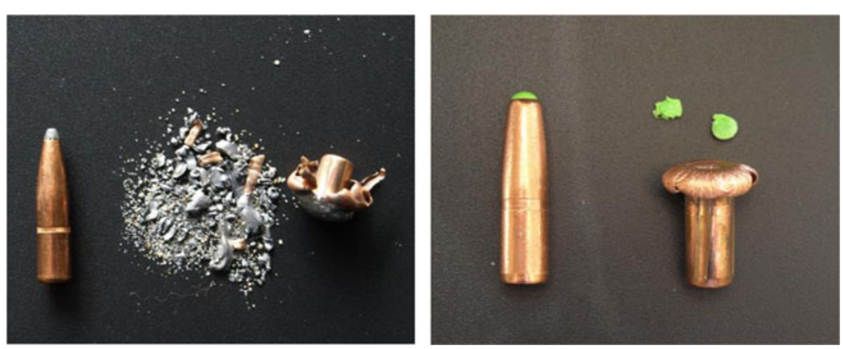

Fig. 7 *Left*: 9 g lead-core bullet (caliber 6.5×55) before and after shooting through water jars. Residual bullet weight is 5.9 g, and approximately 3 g of lead particles and fragments will potentially contaminate the carcass. *Right*: 17.5 g copper bullet (caliber 9.3×62) with a mass reduction of <1 % after passing through similar testing equipment

although being statistically significant is of minor importance under the observed normal hunting conditions.

It is expected that increased impact energy of bullets would reduce flight distance. Gremse and Rieger (2012) show such a relation for impact energies up to 2500 J, but increases beyond 3000 J did not provide any further shortening of the flight distance. In the present study, we have too few impact energy values below 2500 J to conduct a similar analysis. But for impact energy values beyond 3000 J, we cannot demonstrate that increased impact energy resulted in reduced flight distance, either for copper or for lead-core bullets. This suggests that the impact energy of copper bullets is not a limitation of their efficacy, as there is no real difference from the classical lead projectiles. These results show that the impact energy can be seen as a measure of effectiveness only to a certain extent. Gremse and Rieger (2012) indicate that, apart from the critical vital point of impact, the decisive factor for killing ability is the bullet's ability to transform its energy into power and to release it at the right depth in the animal body. Hence, the ballistic behavior of the bullet upon hitting the animal is more important than the bullet material, which is also supported by Gremse and Rieger (2012) and Gremse et al. (2014). This indicates the need of ongoing development of bullet design independently of the material used, especially as it relates to bullet deformation and fragmentation within the animal body (Fackler et al. 1984; Sellier and Kneubuehl 1994; Caudell et al. 2012).

Conclusion

The results of this study and the general experience of the participating hunters indicate that that there is no consistent and significant difference between the efficacy of lead-core and copper bullets for hunting roe and red deer under normal field hunting conditions. These results are in accordance with the studies of Spicher (2008), Knott et al. (2009, 2010), and Gremse and Rieger (2012), which, also, could not detect any major difference between the efficacy of lead-core and copper bullets. The tested copper bullets have an efficacy similar to lead-core ammunition and meet all efficacy requirements for ammunition used in traditional hunting in Denmark. From a lethality and animal welfare point of view, the different brands of non-lead ammunition within the range of bullet calibers and types tested under the reported field conditions can be ecommended as an alternative to lead-core ammunition. However, there is a continuous need to develop non-lead ammunition to satisfy not only an environmental demand but also to improve efficacy, and thereby the ethical sustainability of recreational hunting. Finally, development of hunter education programs and best practice guidance in order to further enhance hunting efficacy is recommended independently of the choice of bullet material.

Acknowledgments We thank the many hunters who took the time to provide all the data we requested. We also thank 15. Juni Fonden, Arboretet, Kirkegårdsvej 3A, DK-2970 Hørsholm for funding all stages of this project. The grant was given for the 3-year study period 2013–2015 (grant number 2013-A-88).

Compliance with ethical standards All of the hunters who participated in the study were fully licensed under Danish law, were experienced hunters, who killed deer according to prevailing ethical hunting standards.

References

Aebischer NJ, Wheatley CJ, Rose HR (2014) Factors associated with shooting accuracy and wounding rate of four managed wild deer species in the UK, based on anonymous field records from deer stalkers. PLoS ONE 9(10), e109698. doi:10.1371/journal.pone.0109698

Bellinger DC, Burger J, Cade TJ, Cory-Slechta DA, Finkelstein M, Hu H, Kosnett M (2013) Health risks from lead-based ammunition in the environment. Environ Health Perspect 121:A178–A179. doi:10.1289/ehp.1306945

Caudell JN, Stopak SR, Wolf PC (2012) Lead-free, high-powered rifle bullets and their applicability in wildlife management. Human Wildlife Interact 6(1):105–111

Caudell JN (2013) Review of wound ballistic research and its application to wildlife management. Wildl Soc Bull 37(4):824–831. doi:10.1002/wsb.311

Cromie RL, Loram A, Hurst L, O'Brien M, Newth J, Brown MJ, Harradine JP (2010) Compliance with the environmental protection (restrictions on use of lead shot) (England) Regulations 1999. Report to Defra, Bristol, p 99

Cruz-Martinez L, Grund MD, Redig PT (2015) Quantitative assessment of bullet fragments in viscera of sheep carcasses as surrogates for white-tailed deer. Human Wildlife Interact 9(2):211–218

Fackler ML, Surinchak JS, Malinowski JA, Brown RE (1984) Bullet fragmentation: a major cause of tissue disruption. J Trauma-Injury Infection Critical Care 24(1):35–39

Golden NH, Warner SE, Coffey MJ (2016) A review and assessment of spent lead ammunition and its exposure and effects to scavenging birds in the United States. Revs Environment Contam Toxicol 237:123–191. doi:10.1007/978-3-319-23573-8_6

Gremse C, Rieger S (2012) Ergänzende Untersuchungen zur Tötungswirkung bleifreier Geschosse. Bundesanstalt für Landwirtschaft und Ernährung (BLE) BMELV – Förderkennzeichen 09HS023. http://www.bmel.de/SharedDocs/Downloads/Landwirtschaft/Wald-Jagd/BLE-Forschungsbericht-Jagdmunition.pdf?__blob=publicationFile.

Gremse F, Krone O, Thamm M, Kiessling F, Tolba RH, Rieger S, Gremse C (2014) Performance of lead-free versus lead-based hunting ammunition in ballistic soap. PLoS ONE 9(7), e102015. doi:10.1371/journal.pone.0102015

Grund MD, Cornicelli L, Carlson LT, Butler EA (2010) Bullet fragmentation and lead deposition in white-tailed deer and domestic sheep. Human Wildlife Interact 4:257–265

Haig SM, D'Elia J, Smith-Eagles C, Fair JM, Gervais J, Herring G, Rivers JW, Schultz JH (2014) The persistent problem of lead poisoning in birds from ammunition and fishing tackle. Condor 116:408–428. doi:10.1650/CONDOR.14-36.1

Kanstrup N (2015) Non-lead rifle ammunition—availability in Danish gun stores. Report 1508–2. Danish Academy of Hunting. 8 p. http://www.danskjagtakademi.dk/fileadmin/user_upload/NK/Bly/

150820_Blyfri_riffelammunition_forhandlerundersoegelse_RAPPORT.pdf.

Knott J, Gilbert J, Green RE, Hoccom DG (2009) Comparison of the lethality of lead and copper bullets in deer control operations to reduce incidental lead poisoning: field trials in England and Scotland. Conserv Evidence 6:71–78

Knott J, Gilbert J, Hoccom DG, Green RE (2010) Implications for wildlife and humans of dietary exposure to lead from fragments of lead rifle bullets in deer shot in the UK. Sci Total Environ 409:95–99. doi:10.1016/j.scitotenv.2010.08.053

Knutsen HK, Brantsæter A-L, Alexander J, Meltzer HM (2015) Associations between consumption of large game animals and blood levels in humans in Europe: the Norwegian experience. In: Delahay RJ, Spray CJ (eds) The Oxford Lead Symposium. Lead ammunition: understanding and minimizing the risks to human and environmental health. Edward Grey Institute, Oxford, pp 44–50

Littell RC, Milliken GA, Stroup WA, Wolfinger RD, Schabenberger O (2006) SAS for mixed models, secondth edn. SAS Institute Inc, Cary

Nadjafzadeh M, Hofer H, Krone O (2013) The link between feeding ecology and lead poisoning in white-tailed sea eagles. J Wildl Manage 77(1):48–57. doi:10.1002/jwmg.440

Pain DJ, Cromie RL, Newth J, Brown MJ, Crutcher E, Hardman P, Hurst L, Mateo R, Meharg AA, Moran AC, Raab A, Taggart MA, Green RE (2010) Potential hazard to human health from exposure to fragments of lead bullets and shot in the tissues of game animals. PLoS ONE 5(4), e10315. doi:10.1371/journal.pone.001031

Sellier K, Kneubuehl BP (1994) Wound ballistics and the scientific background. Elsevier, Amsterdam, p 479

Spicher V (2008) Experiences with lead-free rifle ammunition under field hunting conditions. In: Krone O (ed) Lead poisoning of sea eagles: causes and approaches to solutions—the transition to lead-free rifle ammunition. Leibniz Institut für Zoo- und Wildtierforschung, Berlin, pp 81–90 (In German)

Thomas VG (2013) Lead-free hunting rifle ammunition: product availability, price, effectiveness, and role in global wildlife conservation. AMBIO 42:737–745. doi:10.1007/s13280-012-0361-7

Thomas VG (2015a) Availability and use of lead-free shotgun and rifle cartridges in the UK, with reference to regulations in other jurisdictions. In: Delahay RJ, Spray CJ (eds) The Oxford Lead Symposium. Lead ammunition: understanding and minimizing the risks to human and environmental health. Edward Grey Institute, Oxford, pp 85–97

Thomas VG (2015b) Lead-free rifle bullets: product availability, and issues concerning use in USA. In: Kanstrup N (ed) Efficiency and other aspects of transition from lead to non-lead rifle ammunition. Dansk Jagtakademi, Danish Hunters' Association and 15, Juni Fonden, Aarhus

Trinogga A, Fritsch G, Hofer H, Krone O (2013) Are lead-free hunting rifle bullets as effective at killing wildlife as conventional bullets? A comparison based on would size and morphology. Sci Total Environ 443:226–232. doi:10.1016/j.scitotenv.2012.10.084

Watson RT, Fuller M, Pokras M, Hunt WG (eds) (2009) Ingestion of lead from spent ammunition: implications for wildlife and humans. The Peregrine Fund, Boise, 383