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Improving Animal Welfare in Wildlife Shooting: the Importance of Projectile Energy

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ABSTRACT In wildlife shooting programs, the energy profile of the projectile or bullet (i.e., kinetic energy transferred to the animal), as distinct from caliber (projectile diameter), is an important factor for animal welfare. We examined the role of projectile energy in determining animal welfare outcomes for a typical European rabbit (*Oryctolagus cuniculus*) sharpshooting program. We compared 2 projectiles of different energy profiles: low-energy 40-grain .22

long rifle rimfire (.22LR; 198 J) bullets and high-energy 40-grain .222 Remington® centerfire (.222R; 1,433 J) bullets, fired under similar conditions on 3 nights in September 2014, on a livestock grazing property near Broken Hill, New South Wales, southeastern Australia. We used a thermal-imaging camera to collect antemortem data from 500 rabbits that were shot at varying distance. We collected postmortem data via visual inspection from 482 rabbits that were killed. We used these data to compare 3 animal welfare parameters: wounding rate, duration of suffering, and ballistic injuries. We then used regression modelling to measure the effect of projectile type on these welfare parameters while accounting for shooting distance. All animal welfare parameters indicated that .222R projectiles were more humane than .22LR projectiles. When controlling for distance, for rabbits shot with a .22LR compared with a .222R, the odds of nonlethal wounding increased by a factor of 8 and noninstantaneous death increased by a factor of 9. All animal welfare parameters declined with increasing distance for both projectiles. Our results show that projectile energy and shooting distance were critical determinants of animal welfare outcomes in wildlife shooting programs.

KEY WORDS ammunition, Australia, ballistics, European rabbit, harvesting, *Oryctolagus cuniculus*, thermal imaging, wounding.

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The shooting of wildlife using firearms is a common worldwide wildlife-management activity. Shooting is particularly useful for managing populations considered overabundant (e.g., white-tailed deer [*Odocoileus virginianus*] in the United States; Doerr et al. 2001, badgers [*Meles meles*] in the United Kingdom; Jenkins et al. 2010) or harvested as a resource (e.g., impala [*Aepyceros melampus*] in South Africa; Lewis et al. 1997, kangaroos [*Macropus* spp.] in Australia; Department of Environment and Heritage 2008). There is ongoing concern about the animal welfare outcomes of wildlife shooting programs, particularly the occurrence of animals that are not rendered immediately insensible or those that escape wounded (Stormer et al. 1979, Aebischer et al. 2014). Hampton et al. (2015a) presented a framework

for assessing welfare outcomes in ground-shooting of terrestrial wildlife through the quantification of 4 key parameters: wounding rate (WR), mean time to death (TTD), instantaneous death rate (IDR), and the anatomical location of bullet wounds. However, few terrestrial studies have investigated how changes to operating procedures could improve welfare outcomes (Caudell 2013).

One knowledge gap for terrestrial wildlife-shooting programs is how firearm and bullet configurations influence the outcomes of shooting programs (Caudell et al. 2013). Projectile energy is an important parameter for studies of ballistics and describes the kinetic energy transferred by a projectile to its target, or, in the context of wildlife shooting, animal tissue (Caudell 2013). The kinetic energy delivered is of critical importance for the capacity of physical killing methods to induce instantaneous insensibility. This has been demonstrated for kill-traps (Warburton and Hall 1995), captive-bolt euthanasia devices (Blackmore 1985, Sharp et al. 2015), euthanasia of livestock by shooting (U.S. Department of Agriculture 2004, Thomson et al. 2013), and marine mammal shooting (Daoust and Cattet 2004, Øen and Knudsen 2007, Mörner et al. 2013, Hampton et al. 2015*b*). Projectile energy is also an important determinant of the outcomes of wildlife darting (Valkenburg et al. 1999, Cattet et al. 2006) and archery (Grellner et al. 2004).

Projectile energy differs from projectile caliber; the latter describes the diameter of the projectile but not the velocity it travels with. In common use, 'caliber' is often used to also describe the length of bullet casings (e.g., .22LR vs. .22WMR; Barnes 2009). Kinetic energy is most commonly measured as muzzle energy, describing the energy of the projectile as it is expelled from the muzzle of a firearm (Caudell 2013). As the bullet travels through the atmosphere, it decelerates because of drag, reducing the kinetic energy of the projectile as shooting distance increases (Farjo and Miclau 1997). The kinetic energy of any projectile can hence be calculated at any given distance from the muzzle (e.g., 50 m), but can rarely be controlled for in wildlife-shooting environments. Hence, muzzle energy is a more useful

measure of projectile energy (Caudell 2013). Muzzle energy is most simply expressed in joules (J); the accepted equation for calculating muzzle kinetic energy, E_K , is

$$E_K = \frac{1}{2}mv^2,$$

where m is mass (kg) and v is velocity (meters per second; m/sec; Thomson et al. 2013).

Our objective was to evaluate the role of projectile energy in animal welfare outcomes for wildlife shooting programs. We assessed the performance of 2 projectiles in nocturnal sharpshooting of wild European rabbits (*Oryctolagus cuniculus*). We chose European rabbits as our case study for 3 reasons. First, they were the subject species for a recent study demonstrating the quantification of animal welfare parameters for wildlife shooting methods (Hampton et al. 2015a). Second, European rabbits have a global distribution, are often considered overabundant where they occur, and are commonly controlled by shooting across their range (Angulo and Villafuerte 2004, Henning et al. 2005). Third, a national standard operating procedure (SOP) for shooting European rabbits in Australia stipulates that many different shooting methods and firearm types may be used (Sharp 2012b). Thermal imaging, which has become an important technique for nocturnal wildlife observation (Brawata et al. 2013), was used to observe shooting events following methods used to assess welfare outcomes in the shooting of European badgers in the United Kingdom (Department for Environment, Food and Rural Affairs 2013) and kangaroos in Australia (Hampton and Forsyth 2016).

STUDY AREA

We conducted our study on an extensive livestock grazing property near Broken Hill, New South Wales, southeastern Australia (32°38'S, 144°02'E). The property had a semiarid climate; vegetation was a mixed shrubland–grassland community typical of extensive livestock grazing properties in southern Australia (Dunkerley and Brown 1999). The property had high rabbit densities and was used for commercial kangaroo and rabbit shooting.

METHODS

Field Protocol

We conducted sharpshooting on 3 nights (dusk until dawn) from 6 to 8 September 2014.

Shooting was conducted on nights with clear weather and within 4 days of a full moon. The research was conducted under Murdoch University animal ethics permit O2673/14.

We used a customized Toyota[®] Landcruiser[®] single-cab tray-back utility 4-wheel drive vehicle (Toyota, Toyota City, Japan), with a removable windscreen (as per Lewis et al. 1997) as the platform for the shooter and observer. We used the same observer and shooter to conduct this research because a large volume of data had to be collected in a short period of time for each shot fired, while maintaining awareness of the safety issues present in a shooting environment (Pierce et al. 2015). The observer (JOH) was a veterinarian experienced in collecting animal welfare data from wildlife shooting programs. The shooter was an experienced marksman and accredited sharpshooter for commercial kangaroo harvesting (Department of Environment and Heritage 2008).

The shooter drove the vehicle (5–10 km/hr), as per standard practice in sharpshooting for commercial harvesting in Australia (Department of Environment and Heritage 2008), with the observer standing on the tray directly behind the shooter. A roof-mounted spotlight (100-watt, 240-mm-diam spotlight; Powa Beam, Billinudgel, NSW, Australia), controlled by the shooter, swept back and forth over an arc of 180° but concentrated on the area in front of the vehicle. The shooter located rabbits either directly or by the reflection of light from their eyes.

The shooter used 2 rifles of .22 caliber—a Ruger[®] (Sturm, Ruger and Co. Inc., Southport, CT, USA) .22 long rifle rimfire rifle (.22LR; Table 1) and a Krico[®] (Krico, Pyrbaum, Bavaria, Germany) .222 Remington[®] centerfire rifle (.222R; Table 1). The .22LR rifle was fitted with a Kahles[®] telescopic sight (Kahles, Guntramsdorf, Austria), and the .222R was fitted with a Tasco[®] telescopic sight (Tasco Holdings, Inc., Miramar, FL, USA).

We fixed both telescopic sights on 6× magnification and zeroed the rifles at 50 m prior to shooting. We did not randomize rifle selection, rather, we alternated the 2 rifles every 60 minutes.

We used factory-loaded ammunition. For the .22LR, we used Winchester[®] Power-Point[®] 40-grain hollow-point ammunition (Winchester Australia Ltd., Moolap, VIC, Australia), as per Hampton et al. (2015a). For the .222R, we used Federal[®] V-Shock[®] 40-grain hollow-point polymer-tipped ammunition (Federal Premium Ammunition, Anoka, MN, USA). Both are widely commercially available and commonly used in European rabbit shooting programs in Australia (e.g., Marks 2010, Sharp 2012b). Both projectiles had the same caliber (projectile diam of 0.22 inch) and weight (40 grains) and, hence, sectional density (SD; Table 1). Sectional density is an important ballistic parameter influencing tissue penetration because it represents the ratio of a projectile's mass to its cross-sectional area (see Ordog et al. 1984, Hampton et al. 2015b). The kinetic energy profiles (muzzle energy) of the 2 projectiles were 198 J for the .22LR and 1,433 J for the .222R (Barnes 2009) because of a large difference in muzzle velocity (Table 1). The SOP specifies that rabbits should be shot, with the aid of a spotlight, in the cranium or thorax, with a rifle of minimum .22 rimfire caliber and maximum .223 centerfire caliber (Sharp 2012b).

Animals were shot opportunistically. We did not intentionally select for size. When a stationary rabbit was located and the shooter determined the animal was within 'ethical range' (i.e., the rabbit would likely be humanely killed with a low probability of wounding or missing; Caudell et al. 2009), the shooter engaged the target. The shooter made all decisions regarding which animals to shoot at and from what distance. Because the 2 projectiles we used had very different muzzle velocities (Table 1), and hence capacity for accuracy, the ethical shooting distances were expected to be different, with the shooter expected to observe a shorter ethical range for the less powerful .22LR (Sharp 2012b). At no time was shooting undertaken from a moving vehicle or at a moving animal. Following Sharp (2012b), the

spotlight was focused on the target animal; and the shooter, at their discretion, shot at its thorax or cranium. If a rabbit was wounded but not rendered insensible from the initial shot, the shooter fired follow-up shots at the same animal, as per Sharp (2012b).

Following Hampton et al. (2015a), the observer recorded all shooting events, including the number of shots fired at each animal, shooting distance, time to death for killed animals, and the occurrence of animals that were shot but not killed. We defined time to death (TTD) as the time taken until irreversible unconsciousness and insensibility occurred (*sensu* Daoust et al. 2013), and the observer recorded it as the number of seconds elapsed between the first shot to hit the animal and the moment the animal fell and did not move, with sudden relaxation of the body, including the absence of respiratory movements (Lewis et al. 1997, Daoust et al. 2013, Hampton et al. 2014, Hampton and Forsyth 2016). We defined instantaneous death rate (IDR) as the proportion of animals for which TTD was zero, while we defined wounding rate (WR) as the proportion of animals wounded but not killed in the observation period (*sensu* Stormer et al. 1979). We defined killing efficacy as the proportion of shot animals that were killed (i.e., $[1 - WR]$). However, this definition was limited by requiring death to be visually confirmed and, thus, represents a minimum estimate.

The observer used thermal-imaging observation methods developed for the study of European badger shooting techniques (Department for Environment, Food and Rural Affairs 2013). Thermal imaging has been shown to offer several important advantages over traditional spotlighting for night-based observation of wildlife (Focardi et al. 2001, Brawata et al. 2013). A Guide IR[®] 518C monocular thermal imager (Wuhan Guide Infrared Inc., Wuhan, Hubei Province, China) was used to observe and digitally record all shooting events as per Department for Environment, Food and Rural Affairs (2013). Supplementary Videos 1 and 2 display examples of these recordings in Supporting Information. The observer recorded times to the nearest second using a stopwatch. The distance from the shooter to the rabbit (± 0.5 m) was measured with a Leupold[®] RX[™] II Digital Rangefinder (Leupold and Stevens Inc., Beaverton, OR, USA) immediately after the first shot was fired at the animal. Within 30

seconds after the final shot, the rabbit was approached to confirm death and postmortem investigation was used to assess the extent of ballistic injuries, as per Hampton et al. (2015a).

We recorded gross ballistic injuries to vital and nontarget organs following the principles of Hollerman et al. (1990) and Di Maio (1999). We recorded locations of bullet wounds in the carcass following the methodology of Urquhart and McKendrick (2003), but we recorded all body compartments that had observable ballistic injuries. This method dictated that multiple body compartments could be recorded as displaying ballistic injuries from a single bullet wound. Specifically, we recorded evidence of ballistic injuries to the cranium, neck, thorax, abdomen, and limbs, as per Hampton et al. (2014, 2015a).

Statistical Analysis

Animal welfare parameters.—We included 4 antemortem animal-welfare parameters in statistical analyses: TTD, IDR, WR, and killing efficacy. We estimated the proportion of animals displaying ballistic injuries to SOP-specified anatomical zones (i.e., cranium or thorax) and the proportion of animals displaying ballistic injuries to >1 body compartment. We could not report time to death for animals that escaped wounded because they were still alive when visual contact was lost. We reported means and 95% confidence intervals (CIs) for all parameters as percentages.

Statistical comparisons.—We compared the above parameters between .22LR and .222R calibers. We made these comparisons with generalized linear modelling to examine whether the observed outcomes differed by projectile energy profile (McCullagh and Nelder 1989). These generalized linear models modelled the outcomes (TTD, WR, etc.) as response variables, and projectile energy and distance to rabbit as predictor variables. We used an appropriate link function according to the structure of the outcome data (Table 2).

Survival analysis.—We presented TTD data graphically using a Kaplan–Meier survival estimate (Kaplan and Meier 1958) for each caliber using Graphpad Prism version 4.0 (Graphpad Software, San Diego, CA, USA). We also modelled the effect of different projectiles on time to death (sec) while accounting for the effect of distance using a Cox

Proportional Hazards model (Cox 1972) with the ‘survival’ package in Program R (Therneau and Grambsch 2000, R Core Development Team 2013, Therneau 2014). ‘Hazard’ was the probability of an event occurring in a time period given that it had not already occurred, and in this context it examines the probability of death occurring. We used the Breslow method for events that were tied. We implemented the following model:

$$h(t) = h_0(t)e^{B_1\text{Calibre}+B_2\text{Distance}}$$

where, $h(t)$ = hazard, $h_0(t)$ = the baseline hazard, B_1 is the coefficient for caliber, and B_2 is the coefficient for distance to rabbit.

RESULTS

Antemortem

We examined 500 rabbits shot (including those that escaped wounded) during our study. The greater ethical range of the .222R meant that more rabbits (276) were targeted with this rifle than the .22LR (224). The mean number of shots fired per rabbit was 1.3 (95% CI = 1.2–1.3) for the .22LR and 1.1 (95% CI = 1.0–1.1) for the .222R, accounting for the difference in the number of animals targeted with each rifle. The mean shooting distance for the .22LR was 35 m (95% CI = 33–36 m), and 49 m (95% CI = 47–52 m) for the .222R (Fig. 1). All animals targeted were hit by a projectile.

Time to death

The mean TTD was 10 seconds (95% CI = 7–13 sec) for the .22LR and 2 seconds (95% CI = 1–3 sec) for the .222R (Fig. 2). The TTD for the .22LR increased by 7.5 seconds (95% CI = 3.2–17.7 sec) compared with the .222R while controlling for the confounding effect of shooting distance (Table 2). Results from Cox proportional-hazard modelling revealed that, after controlling for distance, using a .22LR instead of a .222R reduced the hazard of death by 0.66 (95% CI = 0.53–0.81; Table 2).

Instantaneous death rate

The IDR for the .22LR was 66% (95% CI = 59–72%) and 92% (95% CI = 88–95%) for the

.222R. After controlling for the effect of distance, the probability of an animal not being killed instantaneously (noninstantaneous death) increased by a factor of 9 if a rabbit was shot with a .22LR compared with a .222R (Table 2; Fig. 3a).

Wounding rate

The WR for the .22LR was 6% (95% CI = 3–9%) compared with 2% (95% CI = 0–3%) for the .222R. Hence, killing efficacy was 94% (95% CI = 91–97%) for the .22LR and 98% (95% CI = 96–99%) for the .222R. After controlling for distance, the probability of wounding the animal increased by a factor of 8 if a rabbit was shot with a .22LR compared with a .222R (Table 2; Fig. 3b).

Postmortem

The proportion of rabbits with gross ballistic injuries to an anatomical zone specified by the SOP (cranium or thorax; Sharp 2012b), which we will refer to as ‘accuracy,’ was 84% (95% CI = 80–89%) for the .22LR and 89% (95% CI = 85–93%) for the .222R. After adjusting for distance, using the .222R doubled the odds of having a cranium or thorax wound compared with the .22LR (Table 2). The proportions of rabbits with ballistic trauma to multiple body compartments was 7% (95% CI = 4–11%) for the .22LR and 59% (95% CI = 52–65%) for the .222R (Fig. 3c). Using a .222R instead of a .22LR caused a 13-fold increase in the odds of having ballistic trauma in multiple anatomical zones Fig. 3d; Table 2; Supplementary Photo 1, 2).

DISCUSSION

We compared the animal welfare outcomes of using 2 projectiles of identical weight and similar design, but different kinetic energy, in a wildlife sharpshooting program. The percentage of animals with ballistic trauma in SOP-specified target zones was significantly better for the .222R compared with the .22LR, despite mean shooting distances being greater for the former. The role of shooting distance was important with increasing distances leading to poorer welfare outcomes, and particularly so for the .22LR. These results indicate that the projectile with the higher energy profile provided better animal welfare outcomes.

The difference in TTD between the 2 calibers demonstrates a considerable improvement (reduction) in mean duration of suffering associated with the higher energy projectiles. The greater IDR for the higher energy projectiles also demonstrated an improved capacity to induce instantaneous insensibility, the preferred measure for humane killing methods (Newhook and Blackmore 1982, Sharp et al. 2015). The reduced incidence of animals escaping wounded (WR), which is the least desirable animal-welfare outcome from a shooting event (Hampton et al. 2015a), associated with the higher energy projectile demonstrated a considerable animal welfare improvement. Despite variation in the number of shots fired per rabbit and differences in mean shooting distance, a much greater percentage of rabbits shot at with the .222R displayed evidence of ballistic injuries in multiple body compartments. The terminal ballistics of polymer-tipped and hollow-point bullets are similar, with the projectiles designed to disintegrate on impact, maximizing the transfer of kinetic energy to the target (Daoust and Cattet 2004). This result demonstrated that the increased capacity of the .222R to cause insensibility-inducing ballistic injuries was a result of impact energy, rather than increased accuracy.

As a result of differences in transferred kinetic energy, centerfire (typically high-velocity) and rimfire (typically low-velocity) ammunition have been observed to cause substantially different patterns of ballistic injuries. Projectiles considered as 'high-velocity' (>610 m/sec) are generally observed to cause ballistic injuries not limited to the tissues penetrated by the projectile but extend to surrounding structures (Munro and Munro 2008). This wounding pattern is a consequence of the formation of a temporary cavity due to the rapid transfer of kinetic energy. The cavity created by centerfire ammunition may extend to 30 times the diameter of the projectile before collapsing to form the permanent wound tract (Munro and Munro 2008, Caudell 2013). Conversely, the ballistic injury caused by rimfire projectiles was typically limited to the permanent wound tract created by the trajectory of the projectile (Gibson et al. 2015). The postmortem study by Thomson et al. (2013) demonstrated much greater brain tissue ballistic injury in domestic cattle (*Bos taurus*) shot with .22 caliber

centerfire projectiles when compared with .22 caliber rimfire projectiles.

The killing capacity of high-energy centerfire ammunition has been demonstrated in marine mammal studies (Daoust and Cattet 2004, Hampton et al. 2015b). Caudell (2013) asserted that high-energy projectiles appear to cause almost explosive effects on small animals such as prairie dogs (*Cynomys* spp.), which are of a mass similar to European rabbits (Williams et al. 1995). Caudell (2013) argued that this explosive pathological effect is due to the temporary cavity exceeding the elastic limits of the tissues and body compartments of small animals. Courtney and Courtney (2007) demonstrated the capacity of high-energy projectiles to induce unconsciousness ('incapacitation') through the creation of ballistic pressure waves from projectile impacts distant from the central nervous system. Parker et al. (2006) demonstrated the capacity for high-energy projectiles to induce instantaneous death in mammals of approximately 18 kg mass (Eurasian beaver [*Castor fiber*]) that were shot in the abdomen, far distant from the central nervous system. Our observation of many rabbits, shot with high-energy projectiles, with ballistic injuries distant from the permanent wound tract and accompanied by displacement of internal organs (see Supporting Information), supports the assertion of Caudell (2013).

The similar mean accuracy of the .22LR and .222R (84 vs. 89%) was unsurprising given that the shooter was allowed to follow 'ethical range' (Caudell et al. 2009) guidelines and, hence, shooting distances were shorter for the .22LR, as recommended by Sharp (2012b). Previous studies have demonstrated declining shooter accuracy at increasing distance (e.g., Humburg et al. 1982). Hampton et al. (2015a) identified shooting distance as an important explanatory variable for welfare outcomes in rabbit shooting programs. Neither study assessed the role of different firearm configurations. It is acknowledged that a greater risk of nonlethal wounding accompanies the use of low-energy rimfire projectiles over long distances (Sharp 2012a) and, hence, their use is not recommended for the shooting of species with flight responses that require long distance shooting (e.g., red fox [*Vulpes vulpes*]; mean sighting distance of 202 m; Fleming 1997).

For operational shooting programs, there are other important considerations apart from animal welfare. Hoffman (2000) observed that the use of high-energy projectiles (without noise suppression) nearly always resulted in harvested game species becoming alarmed and fleeing, which is an undesirable outcome for meat harvesting and sharpshooting and culling programs with the objective of removing many animals during a set period of time. Escape behavior in response to loud noises can also lead to self-inflicted traumatic injuries in many species (e.g., feral goats [*Capra hircus*]; Tracey and Fleming 2007). However, Hampton and Forsyth (2016) demonstrated that escape behavior of kangaroos during culling was minimized through the use of noise suppression on centerfire firearms. The massive tissue damage induced in multiple body compartments observed with high-energy projectiles, which has also been observed for other harvested species (e.g., harp seals [*Pagophilus groenlandicus*]; Daoust and Cattet 2004) would be a hindrance for meat harvesting programs (Hoffman 2000). High-energy projectiles require high velocity and also possess longer range, raising concerns about overshooting and public safety (Daoust and Cattet 2004, Mawson et al. 2016). For this reason, the use of centerfire ammunition is often prohibited in peri-urban areas where safety concerns are important (Kilpatrick et al. 2002). Hence, the use of high-energy projectiles will not be desirable in all wildlife management contexts, especially where harvesting of meat occurs, where costs are limiting, and in peri-urban areas.

Cost per projectile was >10 times greater for the .222R than for the .22LR. The large cost difference raises questions about the practicality of using more expensive, but more humane, high-energy projectiles (Daoust and Cattet 2004). The cost disparity between low- and high-energy projectiles relates to the concept of “willingness to pay for increased welfare” raised by Warburton et al. (2012:141). If it is accepted that the more expensive option is more humane for professional wildlife-sharpshooting programs, it must be considered who is expected to pay the difference in operating costs if procedures are to be improved (Daoust and Cattet 2004). We contend that high-energy projectiles should be used

when animal welfare, rather than meat harvesting or cost-effectiveness, is the primary concern of a management program.

For physical killing methods that do not rely on projectiles but on anchored penetrating devices (e.g., captive bolts), the ability to induce instantaneous insensibility is largely dictated by the transfer of kinetic energy from the bolt to the cranial vault, as opposed to the direct physical damage caused by the bolt (Daly and Whittington 1989). Even penetrating captive bolts only superficially penetrate into the cerebral hemispheres and thus do not cause direct physical damage to the deeper regions of the brain such as the brain stem, which holds the vital cardiovascular and respiratory centers (Daly and Whittington 1989). As a result, negative animal-welfare impacts have been demonstrated from the use of captive-bolt devices with low kinetic-energy profiles (Sharp et al. 2015). For both wildlife shooting (Daoust and Cattet 2004) and captive bolt (von Wenzlawowicz et al. 2012) studies, it is recognized that accuracy is less critical if projectiles or bolts with high kinetic-energy profiles are used.

Given the lack of consideration that has been given to projectile energy in wildlife shooting policies and procedures, we believe that projectile recommendations should be revisited for many regulated wildlife-shooting programs. For example, the commercial shooting of kangaroos in Australia specifies minimum caliber, but not minimum energy levels for approved projectiles (Department of Environment and Heritage 2008). In contrast, the commercial hunting of young harp seals and grey seals (*Halichoerus grypus*) in Canada is regulated by minimum projectile energy levels, supported by ballistic studies (Daoust and Cattet 2004, Daoust et al. 2013). Eurasian beaver harvesting is similarly regulated in Norway and Sweden (Parker et al. 2006). Consideration of kinetic energy profiles is particularly important with the recent development of commercial low-energy ammunition. Products such as subsonic .22LR rimfire projectiles (Marks 2010, Gibson et al. 2015) and .30 caliber centerfire projectiles (Caudell et al. 2013) have the same caliber as projectiles traditionally used in wildlife management, but have very different energy profiles, transferring much less

kinetic energy to their target. The capacity of high-caliber, low-energy projectiles to facilitate humane killing has been demonstrated to be poorer than for higher energy projectiles (Caudell et al. 2013). Lastly, our study examined animals shot by a single shooter. Given the importance of the identity of shooters in animal welfare studies, results may have differed if multiple shooters were examined (Hampton et al. 2014).

MANAGEMENT IMPLICATIONS

Our study shows that higher energy projectiles can generate superior animal-welfare outcomes for wildlife shooting programs. The drawbacks to the use of high-energy projectiles include increased cost, increased ballistic damage to harvestable meat, increased shooting noise and potential animal disturbance, and increased safety risks related to effective range of shots. Based on our results, we recommend that guidelines for rabbit sharpshooting be reconsidered on the basis that some projectiles allowed under existing protocols possess inadequate kinetic energy to generate desirable animal-welfare outcomes for a considerable proportion of rabbits. We suggest that projectile energy profiles, rather than firearm caliber, should be considered when developing approved methods in regulated wildlife-shooting programs.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Supplementary Video 1. Thermal-imagery observations of typical instantaneous death observed with the use of 40-grain hollow-point polymer-tip .222 Remington® (centerfire) projectiles.

Supplementary Video 2. Thermal-imagery observations of typical noninstantaneous death observed with the use of 40-grain hollow-point .22 long rifle (rimfire) caliber projectiles.

Supplementary Photo 1. Postmortem evidence from rabbits shot once in the neck demonstrates gross ballistic injuries from a 40-grain .22 long rifle caliber bullet.

Supplementary Photo 2. Postmortem evidence from rabbits shot once in the neck demonstrates gross ballistic injuries from a 40-grain .222 Remington caliber bullet.

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Article Summary for Table of Contents. Animal welfare outcomes may be influenced by many factors in wildlife shooting programs. By comparing two different shooting configurations used for the control of European rabbits, we demonstrated that projectiles with greater kinetic energy can generate superior animal welfare outcomes.

Figure Captions

Figure 1. The frequency of shooting distances (m) for vehicle-based sharpshooting of European rabbits with 40-grain .222 Remington[®] bullets (no shading) and 40-grain .22 long rifle bullets (dark shading) in New South Wales, Australia, September 2014. The mean distance for the .222 Remington[®] was 49 m (95% CI = 47–52 m) and for the .22 long rifle was 35 m (95% CI = 33–36 m).

Figure 2. Kaplan–Meier survival comparison for time to death (TTD) between European rabbits shot with 40-grain hollow-point .22 long rifle (rimfire) projectiles (black line) and 40-grain hollow-point polymer-tip .222 Remington[®] (centerfire) projectiles (red line) in New South Wales, Australia, September 2014. The 2 curves were significantly different ($P < 0.001$) but did not control for the confounding effect of shooting distance.

Figure 3. Fitted relationships (mean and 95% CLs) between shooting distance and projectile type (.22 long rifle [black lines] compared with .222 Remington[®] [red lines]) and the probability of instantaneously (a) killing, (b) wounding, (c) hitting an SOP-specified anatomical zone, and (d) inducing ballistic injuries in multiple anatomical zones for a European rabbit shooting program in New South Wales, Australia, September 2014.

Table 1. Ballistic parameters and costs for the 2 projectiles used in our study to compare animal welfare parameters for a shooting program of European rabbits in New South Wales, Australia, during September 2014: .22 long rifle (rimfire) caliber and .222 Remington® (centerfire; Barnes 2009).

Caliber	Firearm type	Projectile wt (grain)	Projectile sectional density (wt/diam ²)	Projectile design	Muzzle velocity (m/sec)	Muzzle energy (J)	Cost per bullet (AUD)
.22 long rifle	Rimfire	40	0.012	Hollow point	390	198	\$0.13
.222 Remington	Centerfire	40	0.012	Hollow point-polymer tip	1,052	1,433	\$1.36

Table 2. Effect of projectile energy on animal welfare outcomes of European rabbits during a shooting program in New South Wales, Australia, conducted in September 2014.

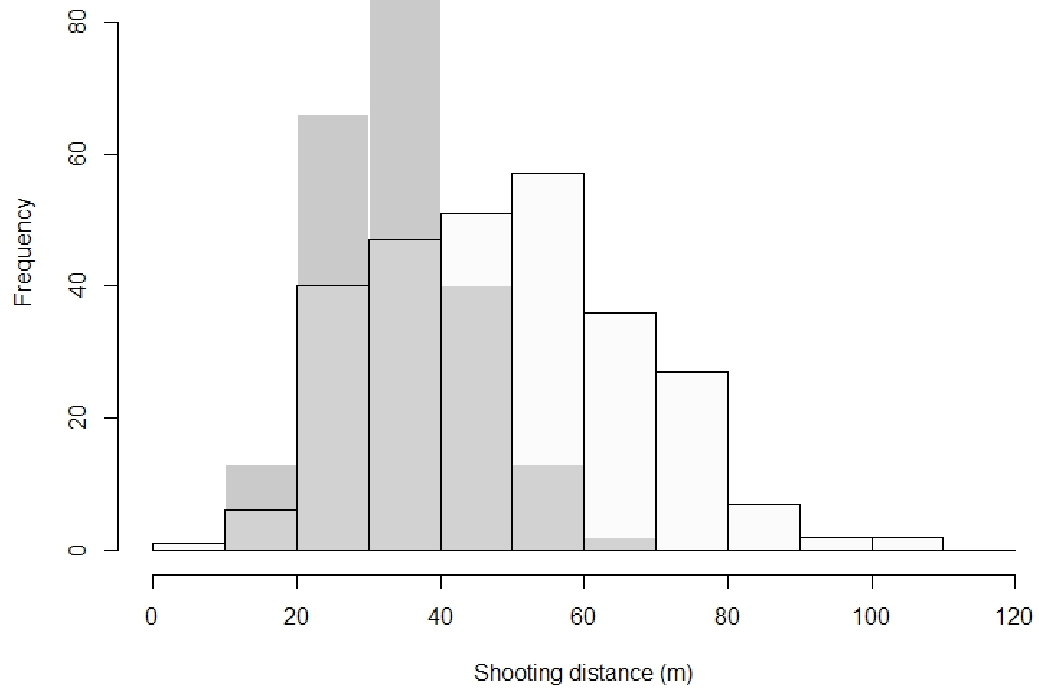
Statistic ^a	Model checking	Model coeff. (and 95% CI) ^b		Interpretation
		Coeff.	95% CI	
			e^{β}	
Mean time to death (TTD)	Poisson goodness-of-fit test: $\chi^2_{479} = 206, P = 1.0$	GLM (negative binomial model link function) to model TTD		Projectile energy has a significant association with TTD. Using a .22LR increases TTD by 7.5 sec while accounting for distance.
		Intercept	0.639 0.177–2.725	
		Distance	1.022 0.996–1.048	
		Projectile energy (baseline .222R)	7.462 3.152–17.666	
Mean time to death (TTD)	Likelihood-ratio test (model cf. intercept only): $\chi^2_2 = 15.8, P = 0.0004$	Cox proportional hazards model to model TTD		Projectile energy has a significant association with TTD. Using a .22LR reduced the hazard function by 0.66.
		Distance	0.996 0.990–1.002	
		Projectile energy (baseline .222R)	0.657 0.534–0.809	

% of animals wounded (WR)	Likelihood-ratio test (model cf. intercept only): $\chi^2_2 = 11.52, P = 0.003$	GLM to model WR		Projectile energy has a significant association with WR. Using a .22LR instead of a .222R caused an 8× increase in the odds of wounding.	
		Intercept	0.002		0.001–0.0147
		Distance	1.044		1.008–1.083
		Projectile energy (baseline .222R)	8.001		2.210–36.613
% of animals instantaneously killed (IDR)	Likelihood-ratio test (model cf. intercept only): $\chi^2_2 = 67.43, P < 0.0005$	GLM to model IDR		Projectile energy has a significant association with IDR. Using a .22LR instead of a .222R caused a 9× increase in the odds of not being instantaneously killed.	
		Intercept	0.024		0.017–0.133
		Distance	1.030		1.001–1.036
		Projectile energy (baseline .222R)	9.220		1.120–3.803
% of animals with ballistic injuries in an SOP-specified area	Likelihood-ratio test (model cf. intercept only): $\chi^2_2 = 6.55, P = 0.0378$	GLM to model SOP-specified wounds		Projectile energy has a significant association with the presence of ballistic injury in an SOP-specified area. Using a .222R instead of a .22LR caused a 2× increase in the odds of having a cranium or thorax ballistic injury.	
		Intercept	0.050		0.017–0.133
		Distance	1.018		1.001–1.036
		Projectile energy (baseline .222R)	2.039		1.120–3.803
% of animals with ballistic injuries in multiple anatomical zones	Likelihood-ratio test (model cf. intercept only): $\chi^2_2 = 107.25, P < 0.0005$	GLM to model multiple anatomical wounds		Projectile energy has a significant association with the presence of ballistic injuries in multiple anatomical zones. Using a .222R instead of a .22LR caused a 13× increase in the odds of having ballistic injuries in multiple anatomical zones.	
		Intercept	0.701		0.357–1.366
		Distance	1.009		0.997–1.022
		Projectile energy (baseline .222R)	12.64		7.233–23.289

^a Each statistic represents a separate outcome measure (e.g., statistics 1 and 2 are both time to death [TTD] but use different multivariable models).

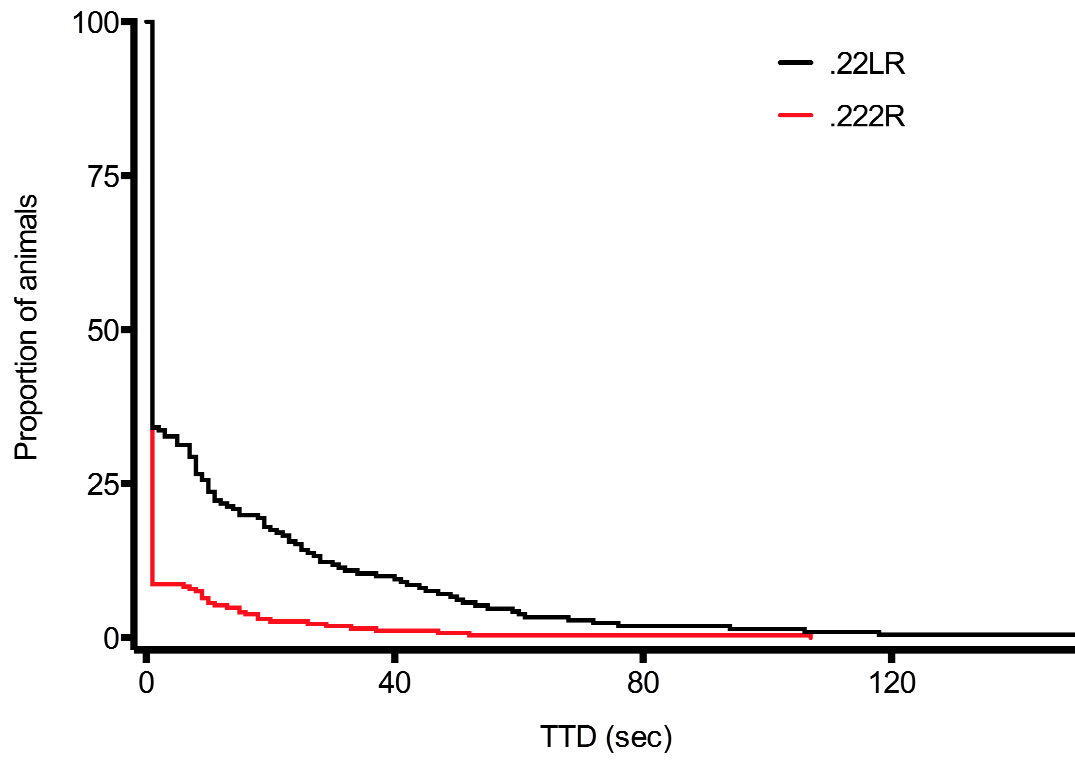
^b A Generalized Linear Model (GLM) was fitted to each outcome variable except the second statistic, where a Cox proportional hazards model was fitted to TTD data.

Figure 1.



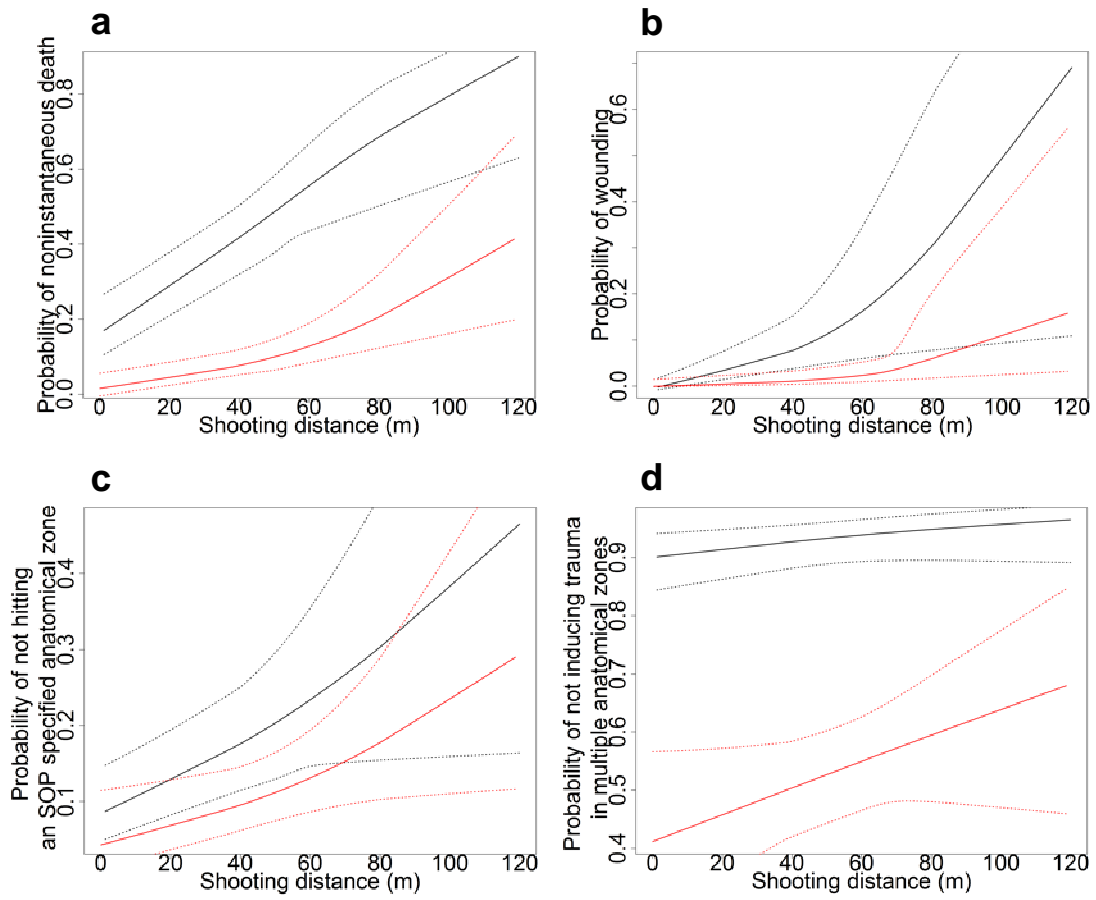
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Figure 2.



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Figure 3.



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