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Force needed to effectively fracture skulls of grey and harp seal beaters using a hakapik

Force nécessaire pour fracturer efficacement le crâne de brasseurs de phoques gris et de phoques du Groenland à l'aide d'un hakapik

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ABSTRACT

The impact force needed to fracture the skull of 6 grey seal young of the year, 9 harp seal young of the year and 3 adult harp seals was examined. The force required to crush adult skulls was greater than that required to crush the skulls of young of the year. Mean velocity resulting in effective blows (damage rating 3 and 4) was 21.44 m/s (n=4) for harp seal young of the year and 27.04 m/s (n=3) for grey seal young of the year. The effective blow velocity was lower for harp seal than grey seal beaters, but differences were not significant due to small sample sizes. Based on a 17.68 m/s velocity that result in an effective blow (damage rating of 3) to a harp seal beater head, effective blows can be delivered by sealers to harp seal beaters on a sustained all day basis. Based on a 24.60 m/s velocity that result in an effective blow (damage rating of 3) to a grey seal beater head, it is less likely that effective blows can be delivered on a sustained all day basis. These recommendations need to be taken with caution as sample sizes were low and we did not test the sustainability of produced velocities.

RÉSUMÉ

La force de coup nécessaire pour fracturer le crâne de six phoques gris jeunes de l'année, neuf phoques du Groenland jeunes de l'année et trois phoques du Groenland adultes a été examinée. La force nécessaire pour fracturer les crânes d'adultes a été jugée plus grande que celle nécessaire pour fracturer le crâne de jeunes de l'année. La vitesse moyenne produisant des coups efficaces (taux d'endommagement de 3 et 4) était de 21,44 m/s (n=4) pour les phoques du Groenland jeunes de l'année et de 27,04 m/s (n=3) pour les phoques gris jeunes de l'année. La vitesse de coup efficace était inférieure pour les brasseurs de phoques du Groenland à celle nécessaire pour les brasseurs de phoques gris, mais les différences mesurées ne sont pas significatives en raison du faible échantillon examiné. En partant de l'hypothèse qu'une vitesse de 17,68 m/s produit un coup efficace (taux d'endommagement de 3) sur le crâne d'un brasseur de phoque du Groenland, les phoquiers peuvent frapper efficacement les brasseurs de phoques du Groenland toute la journée de manière continue. En partant de l'hypothèse qu'une vitesse de 24,60 m/s produit un coup efficace (taux d'endommagement de 3) sur le crâne d'un brasseur de phoque gris, il est moins probable que les phoquiers puissent donner des coups efficaces toute la journée de manière continue. Les présentes recommandations doivent être considérées avec prudence, car les échantillons étaient de petite taille et la durabilité des vitesses produites n'a pas été mise à l'essai.

INTRODUCTION

The killing methods used during the Canadian harp seal (Pagophilus groenlandicus) hunt, which targets beaters (approximately 4-6 weeks old) includes striking the seal beaters on the head with a hakapik or a club to crush the animals' skulls. A hakapik consists of a metal ferrule that weighs at least 340 g with a slightly bent spike not more than 14 cm in length on one side of the ferrule and a blunt projection not more than 1.3 cm in length on the opposite side of the ferrule. The ferrule is attached to a wooden handle that measures between 105 and 153 cm in length and between 3 and 5.1 cm in diameter. The club is made of hardwood that is 60 cm to 1 m in length and that, for at least half of its length, beginning at one end, measures between 5 and 7.6 cm in diameter. Independent groups of veterinarians and biologists have concluded that these tools are effective in resulting in quick kills in relation to the structure of the skulls of these young animals (Daoust et al. 2002, IVWG 2005, and EFSA 2007). However, the European Food Safety Authority also pointed out that there is only a very limited number of studies published in peer-reviewed journals that can be used to evaluate, with a high degree of certainty, the efficacy of the various killing methods employed in different seal hunts around the world (EFSA 2007)

The population of grey seals (Halichoerus grypus) in the northwest Atlantic has expanded considerably during the past few decades, and some members of fishing communities in the Canadian Maritime provinces have expressed a strong interest in developing a hunt for grey seal beaters (of an age group similar to that for the harp seal hunt) for their pelt and blubber (source of omega-3 fatty acids). Hunters have asked for an expansion of the grey seal hunt in order to secure a reliable market for products from grey seal beaters.

It is important that proper methods for killing seals quickly in a manner compatible with sound principles of animal welfare be in place and fully endorsed by the sealing industry and the public. A pilot study conducted by Daoust et al. in early 2009 suggested that there may be important differences between grey and harp seal beater skulls that could influence the efficacy of stunning methods needed to achieve rapid and complete crushing of the cranium. To this effect, a preliminary study was conducted to compare the impact force needed to fracture the skull of grey versus harp seal beaters as a first step to evaluate the efficacy of the harvesting techniques used. This study would also produce recommendations on how to link forces generated by seal hunters to fracture force required for rapid kills.

METHODS

The Canadian hakapik used for the testing was supplied by Dr. Pierre-Yves Daoust of the University of Prince Edward Island, Atlantic Veterinary College. The 3.5 cm diameter octagonal handle was made of wood and was 122 cm long. The hakapik ferrule weighed 347 grams, the blunt projection was 0.8 cm long and the spike was 13.2 cm long (Figure 1). These measurements conformed to marine mammal regulations. SOR/93-56 (http://www.canlii.org/en/ca/laws/regu/sor-93-56/latest/sor-93-56.html).

Two different measuring systems were tested at the Alberta Innovates - Technology Futures (AITF) laboratory in Vegreville, Alberta to measure the force applied by researchers with the hakapik, which were required to effectively fracture the skulls of both harp and gray seal beaters.

Figure 1. Canadian hakapik used to measure forces required to effectively crush the skull of harp and grey seal beaters, March 2010.

The first system involved determining the momentum using an accelerometer attached to a customized computer-based data capture and analysis program. Momentum is obtained by determining the acceleration of the device, integrating it to find the velocity, and multiplying the velocity by the effective mass of the striking component of the hakapik. Acceleration was measured with a Hi-G Schock Isotron Accelerometer, +/-50,000G accelerometer and PCB power supply model 482A22 to provide constant excitation to the accelerometer and transfers the signal to the computer analysis program. The signal is multiplied by 9.81 and divided by the accelerometer constant prior to being integrated to get velocity by the visual basic program and integrated again to obtain displacement. Velocity can then be determined at any displacement from the start position. The velocity immediately preceding the strike was the velocity used to calculate the momentum.

The second technique involved using a FASTCAM-1024PCI high speed camera (High Speed Imaging Inc. Mississauga, ON, Canada) and analyzing the data using ProAnalyst software package (Xcitex Inc. Cambridge, MA, USA). This technique was used to film strikes to determine rotational characteristics that aided in finding the centre of rotation of the hakapik swing which were used to calculate the effective mass, determine the velocity of the hakapik head at the time of impact, and determine the time interval of the hakapik impact which was used to solve for force (F) using the formula:

$$MV=F\Delta t$$

Where
M = effective mass in kg
V = velocity in m/sec
F = force in Newton

Δt = time interval in seconds from contact to zero velocity

It should be noted that the time interval is highly sensitive to the overall motion of the object being struck and the penetration of the hakapik into the object. This overall motion of the struck object increases the time interval and dissipates the force of impact on the skull.

The calculation for effective mass can be expressed as:

$$M_{eq} = I_t / l^2$$

where I_t is the total mass moment of inertia of the striker about the central axis, and l is the distance from the centre of rotation to the centre of the striking point. The mass moment of inertia of a complex shape, with respect to an axis not through the centre of mass, was found by summing the object's mass moment of inertia through its centre of mass (I_c), and the product md^2; where d is the distance to the axis of interest (centre of rotation) from the objects centre of mass and m is the mass of the object. This is known as the Parallel-Axis Theorem, and is represented as:

$$I=I_c + md^2.$$

In this project the centre of mass for each main component has been calculated and then tallied together to calculate the overall centre of mass at the distance d from the overall centre of rotation. Objects with a shape that does not vary in distance from the axis of rotation can be treated as a point mass while all others must be calculated using the Parallel Axis Theorem. The hakapik head is a point mass while the arms of the person and the handle are not as their mass is distributed along their length from the centre of rotation. With the calculated overall centre of mass, the main component of the inertia is calculated as $I = md^2$. The I_c component is then approximated as $I_c = (1/12)ml^2$, which is the general formula for the mass moment of inertia of a rod shape, rotating about its end point, where l is the length from the axis of rotation to the end of the rod. This approximation can be made, since the overall shape of a hakapik even with consideration for the forearms of the person swinging the hakapik is not fundamentally different than a rod shape.

The maximum velocity and momentum generated by 5 different researchers ranging from small female to large male was determined to categorize the relative strength (size) of a person needed to produce effective blows to fracture seal skulls. Maximum momentum strikes to a carpet encased sandbag 20 cm high were filmed with the high speed camera at 3,000 frames per second (fps) and a resolution of 512 by 256 pixels. A sample consisting of three filmed blows were also monitored with an accelerometer to compare the two techniques.

Two of the male researchers were used to deliver blows to 3 adult harp seal, 9 beater harp seal and 6 beater grey seal intact heads (including skin and blubber). Heads were collected from male and female beaters of both harp and grey seals, but differences between sexes were not examined in this study. The adult heads were used to verify the technique and to ensure consistency and validity of the measurements taken on the beater heads. Based on skull morphology, the relative order of momentum needed to crush the seal skulls from low to higher was harp beater, grey beater and harp adult. Seal heads were wrapped in 3 layers of shrink wrap to reduce splatter and placed on sand bags such that the top of the head was 20 cm high to simulate normal seal beater harvest conditions. Blows were filmed with the high speed camera at 6,000 frames per second (fps) and a resolution of 512 by 256 pixels. Striking velocity was varied by changing the arc of rotation of the hakapik club from ~70º to 150º. Each head was struck only once and the strike location recorded. The head was then skinned to assess damage and photographed. Strike locations too far forward and too far to the side were considered bad strikes and treated separately. Strikes near the centre of the calvarium were considered strikes on a hard surface while strikes to parietal surfaces away from the centre line were considered strikes on a soft surface.

Blow effectiveness was rated as:

1. Fail (no visible bone damage or only hairline fractures)
2. Barely Fail (significant fractures with non-displaced skull fragments)
3. Barely Pass (displaced fragment with no significant indentation into the brain)
4. Pass (multiple displaced bone fragments with significant indentation)

Pearson correlation coefficients and linear regression analysis were used to investigate the relationship between force and velocity. Kruskal-Wallis and Wilcoxon two-sample non-parametric tests were used to determine whether velocity and force differed between results and whether velocity and force from good successful strikes differed between the two species of seals. All statistical analyses were done using SAS Release 9.2 for Windows XP (SAS Institute Inc., 2008).

RESULTS AND DISCUSSION

TECHNIQUES

The accelerometer output was not sensitive enough to clearly determine the start and end points of the strike resulting in variance of up to 15% compared to measurements of velocity obtained using the high speed camera. The time interval of the strike began when the club face touched the hair, after which the club head passes through skin, blubber, flesh, bone, and then brain matter. We were not able to detect a difference between contact of soft tissue and background noise from the waveform produced by the accelerometer. Because of the low sensitivity, and thus poor accuracy of the accelerometer output we only used the data obtained from the high speed camera.

The correlation between force and velocity based on all strikes to seal beater heads was not significant ($r=0.45$, $p=0.0933$, Figure 2).

However, when strikes to seal heads were centred on hard bone such that the heads did not roll to the side or back, or forward, force was significantly related to velocity ($r = 0.97$, $p<0.01$, Figure 3).

Because of the inconsistency of the relationship between velocity and force under the conditions of the study, we used primarily researcher number 3 for the strikes on the beater heads and used velocity as the primary measurement of equivalent force. The velocity reported when research number 4 was used would thus be an underestimation of equivalent force.

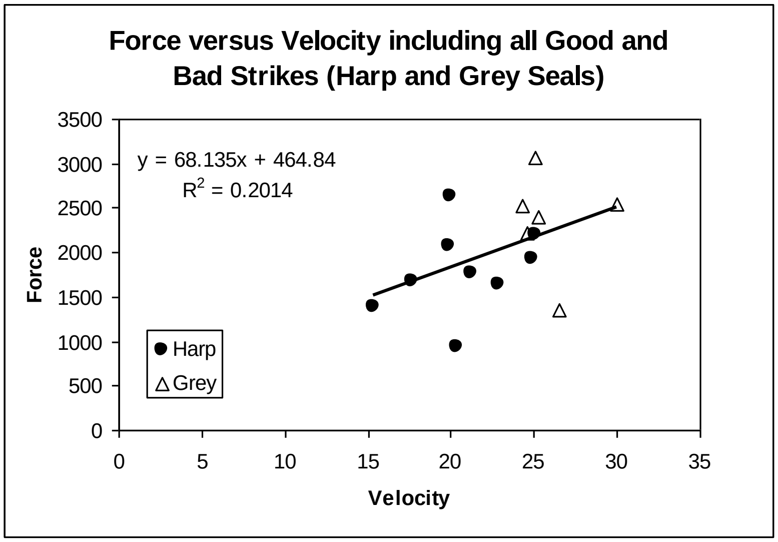


Figure 2. The correlation between force (Newtons) and velocity (m/s) based on all strikes to seal beater heads using a hakapik, March 2010.

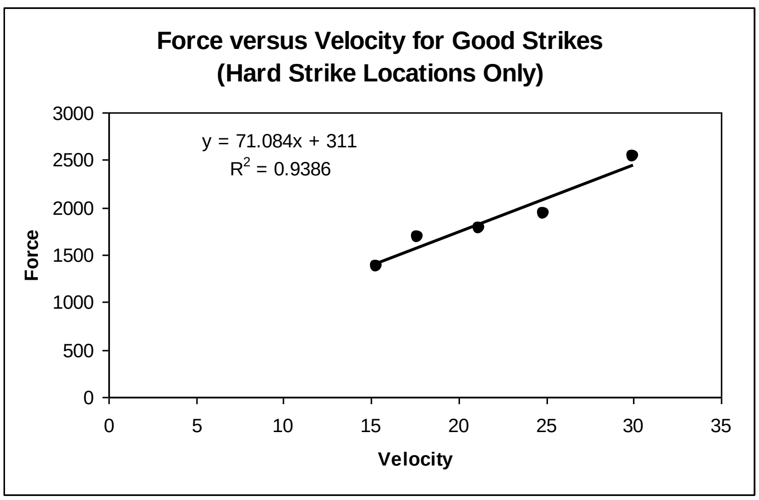
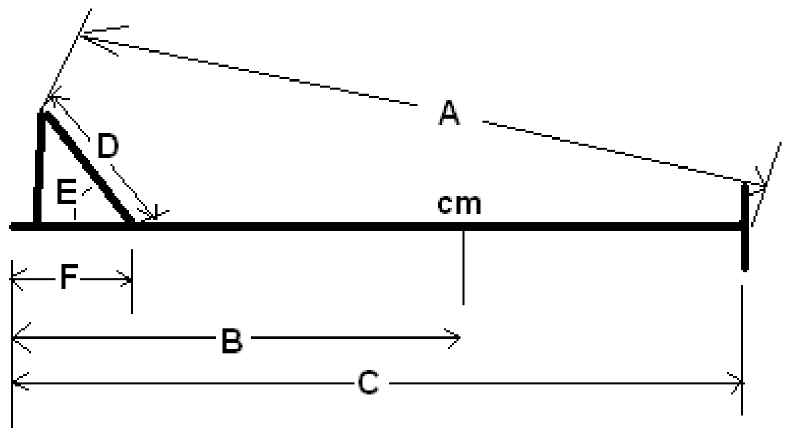


Figure 3. The correlation between force (Newtons) and velocity (m/s) based on good strikes to hard surfaces of seal beater heads using a hakapik, March 2010.

EFFECTIVE MASS

The high speed camera footage indicated that effective mass calculations should include a centre of rotation point slightly beyond the end of the hakapik handle. The style and motion of the hakapik swing implied that the mass contributed by the researcher only included the mass of the forearms. Additionally the relative location of the centre of rotation to the forearms minimized the contribution of one of them (Figure 4).



Item	Measurement
Mass of Club (kg)	1.1719
Distance from club handle end to centre of gravity 'B' (m)	0.803275
Distance from club handle end to centre of striking point 'C' (m)	1.196975
Distance from centre of rotation to centre of striking point 'A' (m)	1.134
Mass of person 4 using hakapik (kg)	72.7
Mass of hand, and forearm	1.31
Angle of forearm 'E' (degrees)	45
Length from centre of grip to centre of rotation (elbow) 'D' (m)	0.32
Distance up handle to centre of right hand 'F' (m)	0.22
Distance up Handle to Centre of Left Hand	0.07
Distance from centre of rotation to centre of Right Arm Centroid (m)	0.22
Distance from centre of rotation to centre of Left Arm Centroid (m)	0.07
Distance from centre of rotation to centre of Mass (combined) (m)	0.294
Total Mass (kg)	3.794
Mass moment of inertia (kg m^2)	0.735
Equivalent mass of Striking Point (kg)	0.571

Figure 4. Diagram and sample measurements used to calculate effective mass of a hakapik strike by researcher number 3 to determine momentum required to effectively crush the skull of harp and grey seal beaters, March 2010.

MAXIMUM PRODUCED VELOCITY

The five researchers striking the carpet wrapped sandbag demonstrated increasing velocity and momentum generated related to size and expected strength except that researcher number 5's velocity was lower than expected (Table 1). He may not have been in as good a physical condition as researcher number 4 or may not have had as good a swinging technique.

Table 1. Maximum velocity using a Canadian hakapik generated by 5 researchers to determine range of forces required to effectively crush the skull of harp and grey seal beaters, March 2010.

Researcher Number	Sex	Height (m)	Weight (kg)	Equivalent Mass (kg)	Velocity (m/s)
1	Female	163	57	NC*	16.61
2	Female	165	61	NC*	17.84
3	Male	168	73	0.571	23.74
4	Male	183	82	0.606	30.27
5	Male	187	91	NC*	25.12

*NC = Not Calculated.

<u>Effective Velocity</u>

Researcher number 3 was unable to generate enough velocity to effectively fracture the skull of adults. However, researcher number 4's strike resulted in an effective blow with skin puncture, multiple displaced bone fragments, and a 2-3 cm indentation in the cranium (Table 2).

Table 2. Velocity and force using a Canadian hakapik generated by 2 researchers to determine range of forces required to effectively crush the skull of adult harp seals, March 2010.

Researcher Number	Effective Mass (kg)	Velocity (m/s)	Force (Newtons)
3	0.571	23.66	1266
3	0.571	25.31	1032
4	0.606	31.74	2509

A strong moderate size male can produce enough velocity (force) to effectively crush the skull of adult harp seals. The required momentum was near the maximum the researcher was able to produce making it unlikely to continue to be effective if many adults needed to be euthanized this way over a short period of time. He would unlikely be able to sustain that level of force over many blows during several hours.

Examples of damage rating 1, 2, 3 and 4 are illustrated in Figures 5, 6, 7, and 8, respectively.

Figure 5. Photo of damage rated as 1 (fail) to a harp seal beater head from a blow using a Canadian hakapik generated by a researcher to determine range of forces required to effectively crush the skulls of harp seal beaters, March 2010.

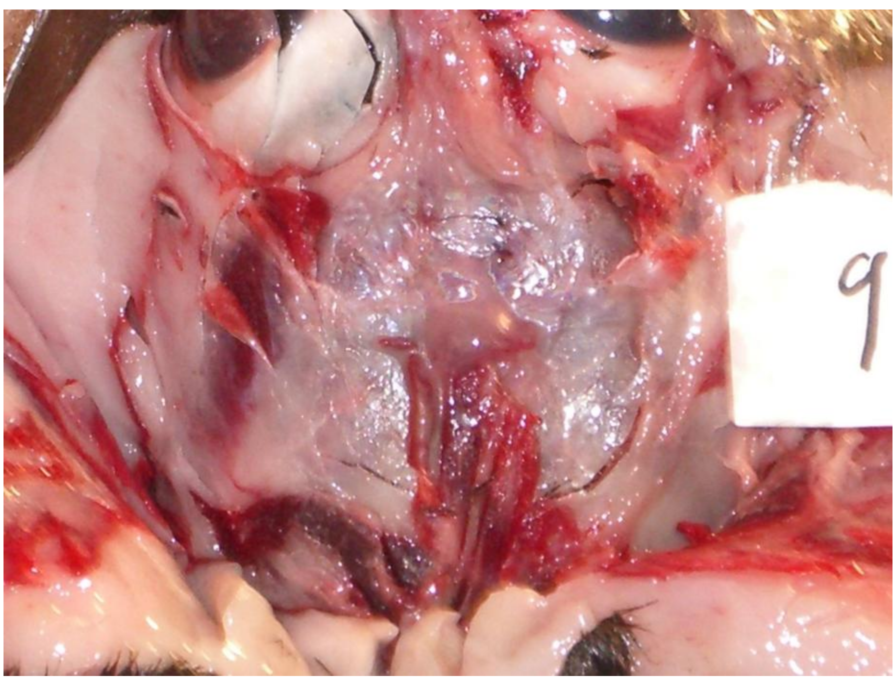


Figure 6. Photo of damage rated as 2 (barely fail) to a harp seal beater head from a blow using a Canadian hakapik generated by a researcher to determine range of forces required to effectively crush the skulls of harp seal beaters, March 2010.

Figure 7. Photo of damage rated as 3 (barely pass) to a harp seal beater head from a blow using a Canadian hakapik generated by a researcher to determine range of forces required to effectively crush the skulls of harp seal beaters, March 2010.

Figure 8. Photo of damage rated as 4 (pass) to a harp seal beater head from a blow using a Canadian hakapik generated by a researcher to determine range of forces required to effectively crush the skulls of harp seal beaters, March 2010.

The velocity and forces applied to harp and grey seal beaters is outlined in Table 3. Mean velocity resulting in effective blows (damage rating 3 and 4) was 21.44 m/s (n=4) for harp seal beaters and 27.04 m/s (n=3) for grey seal beaters. Effective blow velocity was lower for harp seal than grey seal beaters. However, differences were not significant likely because of the small sample size (Wilcoxon two-sample non-parametric test, p=0.1627). With larger sample sizes, these differences would become clearer.

Table 3. Velocity, forces and damages generated by researcher number 3 using a Canadian hakapik to determine range of average forces required to effectively crush the skull of harp and grey seal beaters, March 2010. (damage rating: 1=fail, 2=barely fail, 3=barely pass and 4=pass)

Species Number	Strike Location	Strike Surface	Strike Evaluation	Velocity (m/s)	Force (N)	Damage Rating
Harp 1	Frontal Centre	Hard	Good	21.20	1771	2
Harp 2	Frontal/Nasal Centre	Hard	Bad	25.05	2201	2
Harp 3	Frontal Parietal Centre	Hard	Good	24.85	1935	4
Harp 4	Nasal/Frontal Centre	Hard	Bad	19.95	2629	1
Harp 5	Parietal	Soft	Good	22.88	1634	4
Harp 6	Nasal/Frontal Centre	Hard	Bad	19.90	2069	1
Harp 7	Parietal	Soft	Good	20.36	930	4
Harp 8	Parietal	Hard	Good	17.68	1683	3
Harp 9	Parietal	Hard	Good	15.33	1382	2
Grey 1	Parietal	Soft	Good	26.54	1357	4
Grey 2	Parietal	Soft	Good	24.29	2522	2
Grey 3*	Frontal/Parietal Centre	Hard	Good	29.98	2535	4
Grey 4	Frontal/Nasal Centre	Hard	Bad	25.28	2406	4
Grey 5	Parietal	Soft	Good	24.60	2218	3
Grey 6	Parietal	Soft	Bad	25.07	3068	2

*=researcher number 4.

RECOMMENDATIONS

1. Because of the variable strike locations, soft versus hard strike surfaces and good versus bad strikes, a larger sample size is needed to achieve greater precision and show statistically significant differences. Based on this study we expect that a sample size of about 15-20 animals is needed to statistically evaluate differences. A larger sample would be required to test for possible differences between male and female grey seal beaters.

2. Additional studies should be conducted on seal heads with neck attached, blocked and secured to reduce movement of the head during the strike. Under actual seal hunting situations the live animals reduce this movement using their muscles. This would likely improve the correlation between velocity and force and allow us to evaluate force measurements rather than velocity as an equivalent force measurement.

3. Based on a 17.68 m/s velocity that result in an effective blow (damage rating of 3) to a harp seal beater head we believe that effective blows can be delivered by sealers to harp seal beaters on a sustained all day basis.

4. Based on a 24.60 m/s velocity that result in an effective blow (damage rating of 3) to a grey seal beater head we believe that that effective blows can be delivered by only strong sealers to grey seal beaters on a sustained all day basis. Tiring of sealers would likely lead to greater number of delivered blows below the required force. This recommendation

needs to be taken with caution as our sample sizes were extremely low and we did not test the sustainability of produced velocities.

5. The accuracy of delivered blows is likely related to handle length and practice or skill of the sealer. We suggest that the shorter club would be more accurate to deliver better strike locations. However, a shorter club would likely produce lower velocity and likely have a lower effective mass thereby reducing the striking momentum. Additional complexity is added when we include the shape of the striking component of the club face. Smaller striking surfaces would generate higher pressures at the impact point and penetrate better, resulting in greater bone damage. We suggest testing the club in a similar manner on both harp and grey seal beater heads.

Caution

The measurements of forces exerted on soft tissues are very complex. Because of this complexity and the small sample size used in this study results need to be evaluated with caution.

ACKNOWLEDGEMENTS

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