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Research Paper

Assessment of Noise from Different Types of Rounds Fired from a Saluting Gun

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The difference in sound pressure levels between two types of rounds fired from a saluting gun has been investigated; the rounds being identified as 'current' and 'new'. A 3-pounder saluting gun mounted on a concrete floor based at HMNB Portsmouth, UK, was used in the survey. Sound pressure levels were measured at the two people responsible for operating the gun: the firer and the loader. Twelve current rounds and 24 new rounds were fired during the survey. The new rounds showed a greater variation in peak sound pressure levels between rounds (interquartile range of 2.1 dB, firer's location) compared with the current rounds (interquartile range of 1.1 dB, firer's location). The highest C-weighted peak sound pressure levels for the firer were 173.1 dB for the current round compared with 166.8 dB for the new round. The corresponding highest C-weighted peak sound pressure levels for the loader were 170.6 dB and 163.0 dB, respectively. The difference between median peak sound pressure levels was 8.8 dB for the firer and 9.8 dB for the loader. Similar differences were measured in sound exposure levels between the two types of rounds. Frequency data presented can be used for assessing the suitability of appropriate hearing protectors. Mitigation measures are proposed for further reducing noise exposure of the operators.

Keywords: peak sound pressure level; 3-pounder round; saluting gun; blank ammunition.

1. Introduction

The firing of a saluting gun serves a very specific purpose – this shows a sign of respect or welcome, celebratory or for remembrance. That is, the firing marks a commemoration of an event that occurred in the past, or of a current special occasion. One such important and notable occasion was on 9 September 2022 with the passing of Her Majesty the Queen Elizabeth II (the late monarch of the United Kingdom) whereby 96 rounds (or salutes) were fired during the Death Gun Salute from Hyde Park, London. The number of rounds corresponding to the age of Her Majesty upon death. Similar events with saluting guns and the same number of rounds took place at other locations such as Belfast (Northern Ireland), Cardiff (Wales), Edinburgh (Scotland), and Gibraltar. To mark the occasion, 117 rounds were fired from the saluting guns at Portsmouth Naval Base, UK: 96 to mark Her Majesty's age (upon her demise) and an additional 21 shots as a mark of respect. Other military bases, including Devonport Naval Base Plymouth, UK fired 96 shots to mark the occasion.

Indeed, there are many ceremonial royal occasions within United Kingdom when saluting guns are fired, these include Accession Day, His Majesty the King's Birthday, His Majesty King Charles III's official birthday, Her Majesty the Queen's Birthday, The State Opening of Parliament, and meetings of visiting Heads of State and the Sovereign. The number of gun salutes vary but could include 21, 41, or 61 firings. The salutes are fired in 10-second intervals until all salutes are complete.

There are other guns which are fired on daily basis. One such example is the 'One O'clock Gun' fired from Edinburgh Castle every day at 13:00 to announce the time so that ships could synchronise their chronometric timepieces. Apart from a few exceptions, the gun has been fired every day since 1861. Noting that the speed of sound is approximately 343 m·s^{-1}, *Time gun-maps* (n.d.) were produced to account for the delay in the sound being heard at different distances from the gun. All this, however, is of a historic nature and only serves a symbolic purpose in this technological age. Unsuccessful attempts were made to quieten the noise from the gun on health and safety grounds (Sheridan, 2024).

Only a few published studies were found dealing with the sound pressure levels emanating from the firing of saluting or ceremonial guns and cannons. Primetake, a manufacturer of ammunition for use in ceremonial saluting guns, states that their 25-pounder cartridge (88 mm bore size) with full charge (454 g of gunpowder) would produce a sound pressure level of 160 dB at a distance of 20 m measured at an angle of 90° to the muzzle. The sound pressure level would reduce to 155 dB with a half charge (227 g). However, no data are provided for the locations of the gun operators who would be stationed behind the cannon.

The use of cannons is not restricted for just celebrating royal occasions in the UK. Various types of cannons are regularly used at some universities in the USA (and other countries) to celebrate and commence activities. Peak sound pressure levels of 174 dB have been reported at the operators' locations from ceremonial cannons (Flamme *et al.*, 2019). Based on the findings, it was stated that the sound pressure levels could be '*potentially hazardous*' and that double hearing protection (earplugs and earmuffs) should be worn by those involved in the firings.

The effect and purpose of firing a saluting gun should serve both as an auditory and a visual signal to those in the local vicinity; although the visual effect would only be observable when in line-of-sight with the saluting gun. The event of firing should not cause any harm or injury to any person involved in the firing or observing the firing. The hazards from this activity might include the noise generated, the flash and emission of any gases. It is considered that these three hazards would not pose a significant risk to any observer as there would normally be an area cordoned off around the gun. However, those involved with the firing, nominally the firer and the loader, would necessarily be exposed to these hazards due to the close proximity with the gun. The main premise with regards to noise exposure should be that the firing of the salutes must not affect the hearing of those observing the firing (spectators) and operating the gun.

The noise generated during firing of saluting guns exposes the operators to undesirable sound pressure levels which pose a risk to their hearing. An assessment of the noise from firing of saluting guns based at HMNB Portsmouth showed that the operators might be exposed to C-weighted peak sound pressure levels around 178 dB (Paddan, Howell, 2019). The peak sound pressure produced during firing was considered to be a potential noise risk and this necessitated the need for control measures. One of the main mitigation measures to reduce noise exposure of the operators included recommending the use of a lower charge in the ammunition used in the saluting guns with the aim of maintaining the visual display (flash), but reducing the noise produced (bang). Therefore, based on the recommendation, an opportunity arose to assess the noise from saluting guns firing ammunition with two different types of charge; that is, using the current charge and a new improved lower charge. The data have been assessed using the available guidance specified in (Statutory Instruments, 2005; Directive 2003/10/EC, 2003). Furthermore, the suitability of hearing protection has been evaluated using the procedure in (Ministry of Defence, 2015) using maximum sound pressure levels.

2. Equipment and procedure

2.1. Saluting gun and ammunition

Noise measurements were made during the firing of the 3-pounder saluting guns mounted on concrete platforms at the South Railway jetty at HMNB Portsmouth, Hampshire, UK (Fig. 1). The three land-based guns were aimed towards the water between Portsmouth and Gosport. One of the guns, shown as the gun on the right in Fig. 1 identified as the 'northern gun', was used during the survey. The block number (serial number) of the gun was 538. The gun was manufactured by the Royal Naval Armament Depot, Plymouth. Other identifying marks included 704.R.N.A.D. PLY.1960.

Fig. 1. Saluting guns at HMNB Portsmouth, UK. The right-most gun was fired during the survey.

Two types of 3-pounder blank ammunition identified as 'current' and 'new' were fired during the survey. Further details are shown in Table 1. The survey was conducted such that 24 rounds of the new ammunition were fired first followed by 12 rounds of the current ammunition. There was a gap of about 7 s between successive rounds.

Table 1. Two types of 3-pounder blank ammunition used in the survey.

Type	Identification	No. of round fired	NSN*	Charge	Casing
L1A1 with primer No. 20 L22-A1	Current	12	1305-99-701-2144	11 oz (312 g)	Brass
L6-A1	New	24	1310-98-209-0397	90 g Pyrodex	Plastic

*NSN is the NATO Stock Number, essentially a part number to uniquely identify equipment used by NATO military services.

The gun was operated by two people identified as the 'firer' and the 'loader'. Both people were kneeling with the firer immediately behind the gun and the loader slightly to the right side of the gun. The firer was facing in the direction of the barrel with his head approximately 1.2 m above the concrete mounting base of the gun. The loader faced backwards to the gun and his head was about 1.4 m above the ground (he had the same stance as the firer but was on the plinth). (Although these two workers are identified as the 'firer' and the 'loader', firing a round from the gun involved the following operations: the loader pushes down a lever (seen on the right of the gun in Fig. 1) thus opening access to the barrel, the firer inserts the ammunition into the barrel, the loader pulls up the lever thus closing access to the barrel, the firer pulls the trigger to fire the gun and discharge the round.) Both operators were fully protected with suitable clothing and appropriate gloves including anti-flash hoods over their faces. They wore double hearing protection comprising earplugs (E-A-R soft FX) and earmuffs (Peltor Comtac XPI).

Meteorological data (taken from Ventusky) were recorded which showed the environmental conditions on the day to be a temperature of 9 °C, wind speeds of up to $18\,\text{km}\cdot\text{h}^{-1}$, relative humidity of 70 % and no precipitation.

2.2. Noise measurements

Audio recordings were made near the left ears (about 15 cm away) of the firer and the loader, in accordance with UK Health and Safety Executive guidance on measuring peak noise (Health and Safety Executive, 2021). The microphones for measuring sound pressure levels were mounted on tripods at a 90° incidence (microphone diaphragm parallel to the sound) to the barrel of the gun. Measurements were made using 1/4″ high pressure microphones (40BH, GRAS, Denmark) connected to microphone preamplifiers (26AC, GRAS, Denmark). The microphones were fitted with spherical foam windscreens approximately 65 mm in diameter with a 5-mm hole (WQ-1099, Brüel & Kjær, Denmark). The preamplifiers were connected to the input channels of a microphone power supply (12AA, GRAS, Denmark) and then to the data acquisition and analysis system (DATS Tetrad, Prosig, United Kingdom). The output from the Tetrad acquisition system was connected to a laptop running DATS for Windows software (v4.10.01) where 24-bit rate time histories were acquired simultaneously at a sampling rate of 100 000 samples per second.

Calibration of the complete recording system was carried out using a class 1 pistonphone (42AC, GRAS, Denmark), which gave a sinusoidal calibration tone of 134 dB at a frequency of 250 Hz. The calibration procedure was repeated following the measurement of noise from the gun which showed the equipment to be stable over the measurement period.

2.3. Procedure

The 24 rounds of the new ammunition were fired first followed by the 12 rounds of the current ammunition. There was a 7-second gap between the successive rounds to ensure that there was no interference between the sounds from consecutive rounds. A single computer sound file was saved for each type of round: two time-history waveform files were acquired. Each file was separated into 24 segments for the new ammunition and 12 segments for the current ammunition (each of 0.9 s (±0.1 s) duration) to show the individual rounds in preparation for analysis.

2.4. Analysis of recordings

The human ear does not respond equally at all frequencies, therefore the A-weighting is applied to the audible frequency range to represent the reduction in sensitivity to the low frequencies. The C-weighting filter is suitable for assessing peak sound pressure levels. Long-term noise-induced hearing loss from moderate to loud noise is highly correlated with the noise exposure in dB(A). The mechanism of instant damage to the ear for extremely loud noise is different and is related to peak C-weighted sound pressure levels, L_{Cpeak} (Health and Safety Executive, 2021). The equivalent continuous sound pressure levels (that is, the time-averaged noise levels), L_{Aeq} and L_{Ceq}, are generally calculated for the measured time histories. However, when assessing noise from single events, such as from weapons fire, the L_{Aeq} and L_{Ceq} will be dependent on the period of measurement. In such a case, the A- and C-weighted sound exposure levels are calculated, L_{AE} and L_{CE} (Health and Safety Executive, 2021), indicating the total energy of the signal normalised to a 1-s period. If the measurement comprises a single round, then the L_{AE} is a measure of noise dose per round; the daily noise exposure can be calculated from the number of rounds and the L_{AE} per round. Maximum A- and C-weighted sound pressure levels, the $L_{AF\max}$ and $L_{CF\max}$, were also measured with the time weighting 'F' (with a time constant corresponding to 0.125 s) which replicates the 'fast' meter response of older analogue sound level meters. The time-domain data were processed using a script written in Python© Programming Language. (The results from the Python© script were the same as those when compared with commercially available analysis software including DATS Prosig, *HVLab* (ISVR, University of Southampton) and Brüel & Kjær BZ-5503 'measurement partner suite' software.)

The different parameters calculated were selected so that the sound exposure levels (L_{AE} and L_{CE}) could provide the energy within the waveform signals; and the maximum sound pressure levels ($L_{AF\max}$ and $L_{CF\max}$) could be used for an estimation of the suitability of hearing protection in attenuating the peak noise (Ministry of Defence, 2015).

3. Results

Figure 2 shows example time histories of one current and one new round fired from the saluting gun as measured at the firer's location. Each time history is of 0.1-second duration encompassing the complete waveform for each round. Four, possibly five, positive peaks are seen in the first 0.006 s of the waveform for the round using current ammunition. The peak sound pressure measured for the current round was 11642 Pa corresponding to 175.3 dB, i.e., unweighted (or dB(Z)); this corresponds to the direct sound transmitted from the muzzle of the cannon. The corresponding C-weighted peak sound pressure level is 172.0 dB; this being lower as the C-weighting will reduce the value. The highest peak (minimum) sound pressure level was −7198 Pa (171.1 dB, Z-weighted). The sound pressure had reduced to below 10 % of the peak after about 0.015 s from the start of the waveform (this is referred to as the B-duration; (Department of Defence, 1997)). (The B-duration is defined as the time interval between the peak (either negative or positive) and the last point on the waveform where the value of the pressure has reduced to 10 % of the peak value with succeeding values remaining below 10 % of the peak value (Coles *et al.*, 1968).) The shape of the waveform for the new round is similar to that for the current ammunition, but the values are lower.

a)

b)

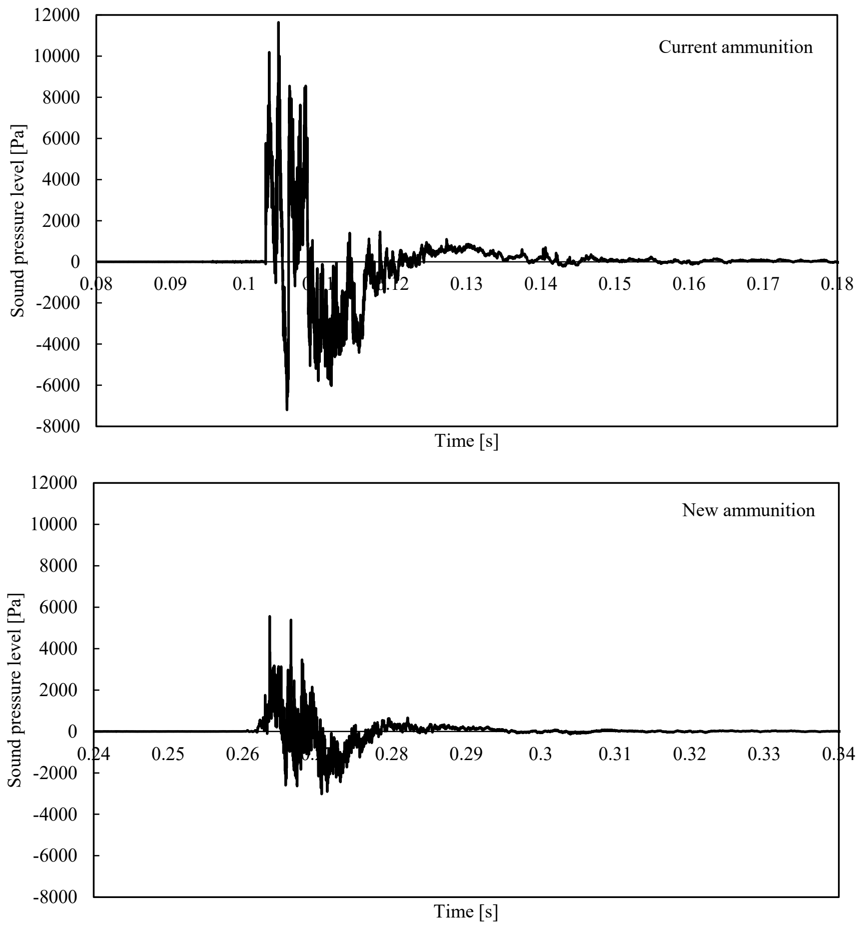

Fig. 2. Sound pressure levels measured near the head of the firer during firing of current and new rounds from the saluting gun.

Table 2. Different parameters for the sound pressure levels measured during firing of current (12 off) and new (24 off) rounds from the saluting gun.

Operator	Ammunition	Parameter	L_{Cpeak} [dB]	L_{AE} [dB]	L_{CE} [dB]	$L_{\text{AF max}}$ [dB]	$L_{\text{CF max}}$ [dB]
Firer	Current	Minimum	170.4	138.7	144.3	147.2	152.6
		Maximum	173.1	142.3	145.9	150.8	154.3
		Median	171.7	141.3	145.4	149.8	153.7
		Interquartile	1.1	0.8	0.4	0.8	0.4
	New	Minimum	158.8	128.2	131.2	136.7	139.6
		Maximum	166.8	135.4	140.7	144.0	149.1
		Median	162.9	131.8	136.1	140.3	144.5
		Interquartile	2.1	1.8	2.3	1.8	2.4
Loader	Current	Minimum	168.1	133.5	141.7	141.9	150.0
		Maximum	170.6	137.3	143.3	145.8	151.7
		Median	169.7	136.6	142.8	145.0	151.2
		Interquartile	1.1	0.7	0.2	0.7	0.2
	New	Minimum	154.2	122.7	128.7	131.1	137.1
		Maximum	163.0	129.4	137.7	138.0	146.2
		Median	159.9	126.8	134.3	135.2	142.8
		Interquartile	3.1	2.8	2.0	2.9	2.0

The peak sound pressure for the new round was 5559 Pa (unweighted (Z) value of 168.9 dB, C-weighted value of 164.1 dB). The B-duration for the new round was 0.019 s. It is noted that although B-durations are presented for the different waveforms, these are not used in the assessment procedures. Both waveforms show many peaks and troughs of unknown origins, possibly relating to reflections from the various structures around the gun (such as the other guns, and solid concrete bases as shown in Fig. 1).

Table 2 presents the sound pressure levels measured for the firer and loader locations with the current and new ammunition rounds. Various parameters based on the number of rounds fired are also presented; 12 rounds of the current type and 24 rounds of the new type. The highest C-weighted peak sound pressure level measured with the current type of round was 173.1 dB, and that with the new type of round was 166.8 dB; both measurements being at the firer's location.

3.1. Peak sound pressure level, L_{Cpeak}

Figure 3 shows the peak sound pressure levels, L_{Cpeak}, measured at the firer's and loader's locations during the firing of both current and new rounds. The variation between individual rounds can be seen. It is clear that the current rounds, shown as red and green circles, show higher values compared with the new rounds, shown as blue and yellow circles. The greatest difference between the rounds is seen for measurements at the loader with new rounds: round 6 shows a C-weighted peak of 154.2 dB compared with 163.0 dB for round 4 – a difference of 8.8 dB. The new rounds showed higher variation (interquartile range)

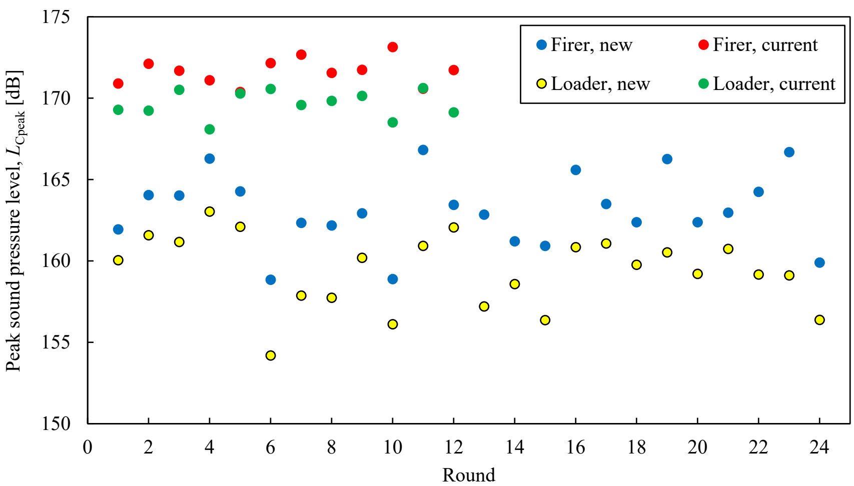

Fig. 3. Peak sound pressure levels (L_{Cpeak}) measured at the firer and the loader during firing of current and new rounds from the saluting gun.

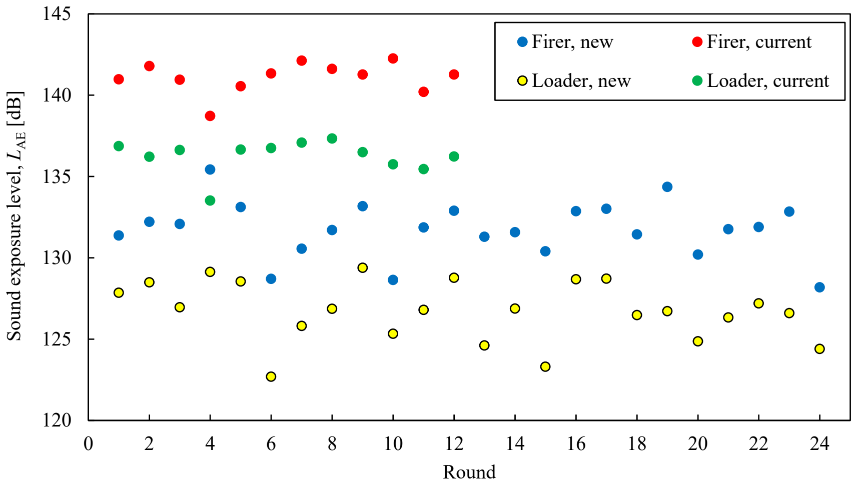

Fig. 4. Sound exposure levels (L_{AE}) measured at the firer and the loader during firing of current and new rounds from the saluting gun.

in peak sound pressure levels compared with the current rounds (see Table 2). Based on the median peak sound pressure levels, the L_{Cpeak} at the firer and the loader for the current ammunition was 8.8 dB and 9.8 dB higher, respectively, compared with the new rounds. Higher L_{Cpeak} values were measured for the firer compared with the loader ($p < 0.01$ for both types of rounds, Student's t-test): 2.0 dB higher for the current rounds and 3.0 dB higher for the new rounds (see median values in Table 2).

3.2. Sound exposure level, L_{AE} and L_{CE}

A- and *C*-weighted sound exposure levels (L_{AE} and L_{CE}), which provided the noise level normalised to a one-second period, were calculated for each round. For transient noise, such as that associated with weaponry, sound exposure level is a more convenient and preferred measure compared with the equivalent continuous sound pressure level (L_{Aeq}) as it effectively shows the total noise energy per round fired. Table 2 shows the L_{AE} and L_{CE} values for the two types of rounds and for the two operators. Sound exposure levels (L_{AE}) measured for the different combinations of round and location are shown in Fig. 4. The differences in the L_{AE} values are quite clear: the current rounds show higher values compared with the new rounds (difference between median values of 9.5 dB for the firer and 9.8 dB for the loader), and the firer was exposed to higher values compared with the loader (difference between median values of 4.7 dB for the current rounds and 5.0 dB for the new rounds).

The frequency spectra of the different combinations of rounds and measurement locations for the firings from the saluting gun are shown in Fig. 5. The data show the mean and range (minimum and maximum) sound exposure levels (L_{ZE}) corresponding to the 12 current rounds and 24 new rounds fired from the gun.

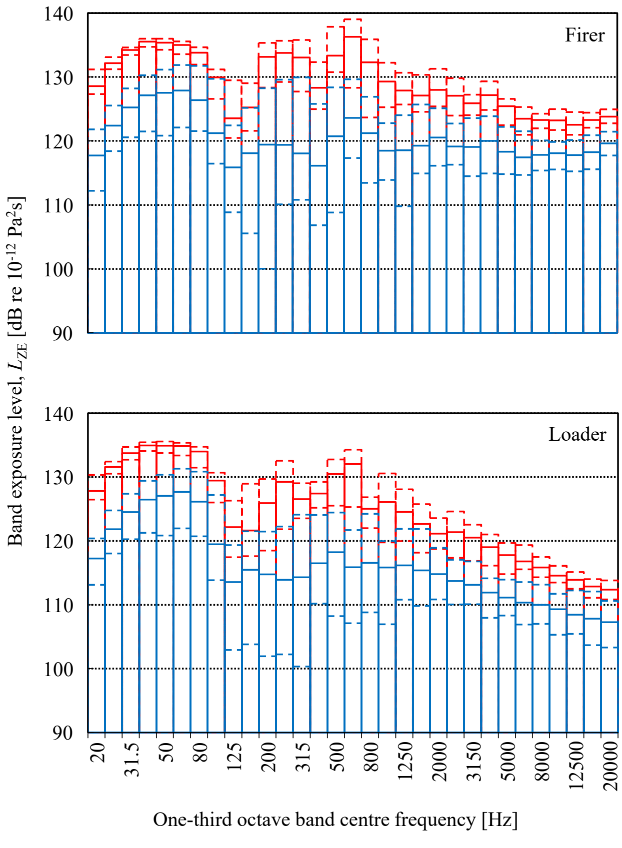

Fig. 5. One-third octave band sound exposure levels L_{ZE} (mean (solid line) and range (dashed line) corresponding to 12 current and 24 new rounds) measured for the current (red line) and new (blue line) rounds.

Without exception, the mean sound exposure levels at the one-third octave frequency bands for current rounds were higher than the new rounds fired from the gun. When averaged over the frequency bands from 20 Hz to 20000 Hz, the current rounds produced sound exposure levels (L_{ZE}) approximately 8.7 dB higher for

Table 3. Median values for the maximum fast sound pressure levels and sound exposure levels measured during firing of rounds from the saluting gun.

Location, round	$L_{\mathrm{AF\,max}}$ [dB]	$L_{\mathrm{CF\,max}}$ [dB]	L_{AE} [dB]	L_{CE} [dB]	$L_{\mathrm{CF\,max}} - L_{\mathrm{AF\,max}}$ [dB]	$L_{\mathrm{CE}} - L_{\mathrm{AE}}$ [dB]
Firer, current	149.8	153.7	141.3	145.4	4.0	4.2
Firer, new	140.3	144.5	131.8	136.1	4.1	4.1
Loader, current	145.0	151.2	136.6	142.8	6.2	6.3
Loader, new	135.2	142.8	126.8	134.3	7.0	7.0

the firer and 8.6 dB higher for the loader than the new rounds, respectively. Most of the sound energy was present in frequencies below about 100 Hz.

3.3. Maximum sound levels, $L_{\mathrm{AF\,max}}$ and $L_{\mathrm{CF\,max}}$

Various parameters about the sound levels measured during firing of different types of round and location are shown in Table 2. The parameters L_{Cpeak}, L_{AE}, and L_{CE} do not give an indication of the frequency content present within the sound. These either show a single value within the signal (L_{Cpeak}) or the total energy present in the signal (L_{AE} and L_{CE}). The *difference* between the A- and C-weighted maximum sound levels, $L_{\mathrm{AF\,max}}$ and $L_{\mathrm{CF\,max}}$, can, however, give a broad indication of the frequency content of the signal. (Although, the spectra shown in Fig. 5 would give a better measure of the differences at the various frequencies.) The differences between the A- and C-weighted levels for both sound exposure levels (L_{E}) and maximum sound levels ($L_{\mathrm{F\,max}}$) were therefore calculated for each of the current and new rounds fired from the cannon; median values are shown in Table 3. Table 3 also shows the median differences between A- and C-weighted levels for the two measurement locations (that is, the firer and the loader). Various findings become evident from the data. The differences between C- and A-weighted values are lower for the firer's location than the loader's position; this being the case for both the current and the new rounds. This would indicate that the sound measured at the firer's location contained a higher proportion of high-frequency energy compared with the loader's location; this is confirmed by the spectra shown in Fig. 5. There appears to be only a small difference between the maximum sound levels ($L_{\mathrm{CF\,max}} - L_{\mathrm{AF\,max}}$) and the exposure levels ($L_{\mathrm{CE}} - L_{\mathrm{AE}}$) when comparing data for the current rounds (0.2 dB for the firer and 0.1 dB for the loader). Overall, it is seen that there are only very marginal differences when using either the sound exposure levels or the maximum sound levels.

4. Discussion

The noise measurements for the saluting gun being used with the two types of rounds show that, at the firer's location, the C-weighted peak sound pressure level, L_{Cpeak}, for the new type of round (162.9 dB) was about 8.8 dB lower than the current round (171.7 dB). The difference was higher (9.8 dB) for the loader's location. The corresponding differences between sound exposure levels, L_{AE}, were 9.5 dB for the firer and 9.8 dB for the loader's position. This represents a significant decrease in the exposure of the two operators during firing of the gun with the new rounds compared with the current rounds. It could be argued that one of the drawbacks of the lower noise levels is that people in the local vicinity are not able to hear the noises made in a celebratory nature. This consequence, however, should be considered as acceptable and that the health of the operators would (should) outweigh this concern.

Table 2 shows that the variation (interquartile range) in the different sound parameters was greater for the new rounds compared with the current rounds. For example, for measurements made at the loader's position, parameters L_{CE} and $L_{\mathrm{CF\,max}}$ show that there was 10 times as much variation between rounds for the new ammunition (2.0 dB) compared with the current ammunition (0.2 dB). This large variation for the new rounds is also seen in the unweighted sound exposure levels L_{ZE} calculated in the one-third octave bands as shown in Fig. 5. (It is noted that twice as many of the new type of rounds (24 rounds) were fired compared with the current type (12 rounds).) It is assumed that this difference in noise between successive rounds would be no cause for concern due to the purely commemorative nature of the activity. The source of the variation is, however, not known. One of the factors that might influence this variation could be the specification, or tolerance, used in the manufacture of the rounds. If that were to be the case, then this might imply that the new rounds were manufactured to a lower standard compared with the current rounds. However, such inferences might cause differences of opinion with the manufacturers of such items. A similar discussion has been presented regarding the slightly higher variation (though inconclusive) in sound pressure levels measured when firing blank rounds from three military rifles compared with live rounds (Paddan, Howell, 2022). It was opined that the blank rounds, which are used for educational and training purposes, might be manufactured to less stringent standards compared with the tighter tolerances used when producing live rounds. All this discussion is based on speculation; this topic, however, requires evidence.

Two frequency weightings, A and C, appropriate for exposure to noise were used in the assessment of sounds produced by the rounds fired from the saluting gun (further details about the frequency weightings for sound level meters are shown in (British Standard Institution, 2013)). The C-weighting filter is more appropriate for assessing peak sound pressure levels normally found in impulse or impact signals. Long-term damage to hearing from moderate to loud noise is related to the noise exposure calculated using the A-weighting. It is noted that the A-weighting amplifies the sound pressure levels over the frequency range 1000 Hz to 6000 Hz. Sound exposure levels (L_{ZE}) for one-third octave frequency bands are shown in Fig. 5 for the two types of rounds. Most of the energy in the impulse signals for the new rounds occurred at frequencies below about 100 Hz.

The suitability of hearing protection that can be used to protect the operators from the impulse noise can be determined using the frequency data presented in Fig. 5. Further details about the process involved are given in (Health and Safety Executive; 2021). A method specifically for determining suitable hearing protection for use with military weapons is given and mandated in (Ministry of Defence, 2015). The method is based on using the difference in the maximum sound levels; this is calculated as $L_{\text{CF max}} - L_{\text{AF max}}$. This is used to give a broad indication of the frequencies present in the noise signal. It is seen from Table 3 that the same information can be gleaned from the sound exposure levels: L_{AE} and L_{CE}. The difference between L_{CE} and L_{AE} can provide the same information as the maximum sound levels (that is, $L_{\text{CF max}} - L_{\text{AF max}}$). The development of Defence Standard 00-027 (Ministry of Defence, 2015) is discussed elsewhere (Paddan, Howell, 2025).

The suitability of the hearing protection worn by the firer and the loader can be made using the attenuation properties of the hearing protection combination of earplugs (E-A-R soft FX) and earmuffs (Peltor Comtac XPI), and details about the noise produced. The attenuation properties of this combination of hearing protection were 42 dB for high (H) frequencies, 44 dB for medium (M) frequencies, and 42 dB for low (L) frequencies; the SNR (single number rating) was 45 dB (INSPEC, 2017). For the assessment, the highest L_{Cpeak} of 173.1 dB can be used corresponding to the firer's noise exposure while using the current ammunition (see Table 2). The difference between the two parameters, $L_{\text{CF max}}$ and $L_{\text{AF max}}$, is required to determine the suitability of hearing protection as specified in (Ministry of Defence, 2015); these are shown in Table 3. The guidance (Ministry of Defence, 2015) states that this difference would then be used to calculate a 'modified sound attenuation value, d_m' as shown in Table 4. Table 3 shows this difference to be between 4.0 and 7.0 depending on the operator (firer or loader) and type of ammunition (current or new). The effective sound pressure level at the ear, L'_{Cpeak}, is calculated:

$$L'_{\text{Cpeak}} = L_{\text{Cpeak}} - d_m. \tag{1}$$

Table 4. Modified sound attenuation values for different impulse or impact noises (adapted from Ministry of Defence, 2015); H = high, M = medium, L = low.

$L_{\text{CF max}} - L_{\text{AF max}}$ [dB]	Modified sound attenuation value, d_m [dB]
≤0	H
>0 to 1	M
>1 to 3	M – 5
>3 to 5	L or M – 5 if a lower value
>5 to 10	L – 5
>10	Conditional use of L – 5

Table 5 shows the effective sound pressure level at the ear, L'_{Cpeak}, based on the attenuation properties of the E-A-R soft FX earplugs worn in combination with the Peltor Comtac XPI earmuffs. The C-weighted peak sound pressure at the ear would be below the exposure limit value, corresponding to 140 dB, specified in (Statutory Instruments, 2005; Directive 2003/10/EC, 2003).

The sound pressure levels measured during firing of the saluting gun with the two types of rounds can be compared and assessed using the guidance in (Statutory Instruments, 2005; Directive 2003/10/EC, 2003). These documents specify the following:

1) the lower exposure action values (LEAV) are:
   - a daily or weekly personal noise exposure of 80 dB (A-weighted);
   - a peak sound pressure of 135 dB (C-weighted);

Table 5. Effective sound pressure level at the ear for the loader and firer when using current and new ammunition. Hearing protector (E-A-R soft FX earplugs worn in combination with Peltor Comtac XPI earmuffs) – H = 42 dB, M = 44 dB, L = 42 dB.

Location, round	$L_{\text{CF max}} - L_{\text{AF max}}$ [dB]	Modified sound attenuation value, d_m [dB]	Effective sound pressure level at the ear, L'_{Cpeak} [dB]
Firer, current	4.0	M – 5 = 39	134.1
Firer, new	4.1	M – 5 = 39	134.1
Loader, current	6.2	L – 5 = 37	136.1
Loader, new	7.0	L – 5 = 37	136.1

2) the upper exposure action values (UEAV) are:
   - a daily or weekly personal noise exposure of 85 dB (A-weighted);
   - a peak sound pressure of 137 dB (C-weighted);
3) the exposure limit values (ELV) are:
   - a daily or weekly personal noise exposure of 87 dB (A-weighted);
   - a peak sound pressure of 140 dB (C-weighted).

It is noted that the 'daily personal noise exposure' is standardised to an 8-hour period and the 'weekly personal noise exposure' is standardised to five 8-hour working periods (40 h per week). Data in Table 2 show peak sound pressure levels, while data in Table 5 correspond to the peak sound pressure levels *after* taking into account the attenuation provided by the hearing protection. These data have been compared with the peak sound pressure level (peak sound pressure level at the ear $L'_{\text{Cpeak}} = 140\,\text{dB}$) as shown earlier. An assessment with respect to the 'daily personal noise exposure' would require a measurement of L_{Aeq} over an 8-hour period. The sound exposure level, L_{AE}, which is a measurement standardised for a 1-second period, can be used. This comparison can also be carried out by calculating the exposure levels in terms of sound exposure values: the LEAV would be L_{AE} 124.6 dB, UEAV would be L_{AE} 129.6 dB, and the ELV would be L_{AE} 131.6 dB. It is seen from Table 2 that, apart from the loader's position during firing of the new rounds, the median sound exposure levels for the other combinations (operator and type of round) exceeded the UEAV (L_{AE} 129.6 dB). However, it must be emphasised that an assessment with respect to the 'daily personal noise exposure' can only be carried out if the peak sound pressure level has not been exceeded.

It is clear from the data that the new rounds produce lower sound pressure levels compared with the current rounds, and that the firer is exposed to higher levels compared with the loader. Further mitigation measures should be considered in reducing noise exposure of the two operators. Some of the measures proposed might not be practicable or feasible but should nonetheless be considered. Also, some of the suggestions might be deemed as being controversial or unpalatable to the operators (or those in command), but these difficult questions should be addressed. There would need to be a fine balance between ceremony and safety. Some of the measures could include the following:

- In theory, sound pressure levels decrease by 6 dB with doubling of distance from the noise source. That is, increasing the distance between the gun and the operators would result in a significant decrease in exposure. One such measure could be to automate the firing of the gun or to operate the firing mechanism from a distance.
- The firer is exposed to higher sound pressure levels compared with the loader. Rotating (sharing) the jobs carried out by the two operators could be considered such that the firer and the loader alternate their duties between successive rounds. This would ensure that no single operator is continuously exposed to high noise levels. It is noted that this suggestion might impinge on the firing rate (the period between) of successive rounds. The standard period between successive salutes is nominally 10 s.
- The frequency spectra for the two types of rounds show a dominance in sound pressure levels for frequencies below about 100 Hz. Hearing protectors are generally less effective at attenuating low frequencies compared with high frequencies. If possible (and available), careful selection of hearing protection could involve showing preference to those protectors likely to offer greater protection over low frequencies.
- A barrier or screen could be placed between the muzzle of the gun and the two operators. This could take the form of a solid plate attached to the gun thus creating an 'acoustic shadow' around the operators. Depending on the design of such a screen or enclosure, this might be expected to reduce the sound pressure level by a few decibels. The barrier would alter the noise received by the operators and might influence the choice of hearing protection worn by the operators.
- The number of rounds, or salutes, is dictated by ceremony and tradition. Maybe fewer salutes could be conducted to mark 'regular' occasions. This would not discourage increasing the number of salutes, as necessary, to mark extraordinary events; one such event being the 96 salutes to mark the passing of Her Majesty the Queen Elizabeth II.

5. Conclusions

Noise measurements were made from the firing of two types of rounds from a saluting gun: the current round and a new round. Measurements were made at the firer's and the loader's positions. Twelve rounds of the current ammunition and 24 rounds of the new ammunition were fired during the assessment. The highest C-weighted peak sound pressure levels for the firer and the loader were 173.1 dB and 170.6 dB, respectively for the current round and, 166.8 dB and 163.0 dB, respectively, for the new round. Lower peak sound pressure levels were measured when new rounds were fired compared with the current rounds: the difference in median peak sound pressure levels were

8.8 dB and 9.8 dB for the firer and the loader, respectively. Sound exposure levels, a parameter which is normalised to a period of 1 s, again were higher for current rounds (A-weighted median values of 141.3 dB and 136.6 dB for the firer and loader, respectively) compared with new rounds (A-weighted median values of 131.8 dB and 126.8 dB for the firer and loader, respectively).

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Disclaimer

The contents of the work, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect the policy of UK Ministry of Defence.

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