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The Effect of Ambient Temperature Variation to The Muzzle Energy of Airguns

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Abstract

Since airguns can be lethal when they possess high enough muzzle energies, airguns with wounding capability are strictly controlled by the Control Act of Firearms, Ammunitions, and Blades (the Act) in Taiwan. Forensic tests are always required to determine the wounding capability of confiscated airguns. Thus the accuracy and consistency of wounding capability tests are very important for the enforcement of the Act. Because muzzle energies of carbon dioxide type airguns have been reported to be affected by the variation of ambient temperatures, the effect of temperature variation to the muzzle energies of spring piston and pneumatic type airguns were investigated in this study. A paired Student's t test indicated that the elevated ambient temperature resulted in significant increase of muzzle energy for both spring piston and pneumatic airguns. Besides, the number of pumping strokes of a multi-pump pneumatic airgun was also found to significantly affect the muzzle energy of the airgun. Thus while conducting wounding capability tests of airguns the ambient temperature should be precisely controlled and the multi-pump pneumatic airgun should be test fired at varied pumping strokes recommended by the owner's manual to avoid any mistakes caused by temperature fluctuation and incomplete testing procedures.

Keywords: forensic science, firearms examination, airguns, muzzle energy, wounding capability.

Introduction

Although airguns are usually involved in less severe crimes such as injuries and vandalism, they can still be lethal weapons when their muzzle energies are high enough. Thus the civilian possession of airguns capable of causing gunshot wounds is severely restricted by The Control Act of Firearms, Ammunitions, and Blades (The Act) in Taiwan. Illegal possession of airguns with wounding capability could be sentenced to a penalty between 3 and 10 years in prison [2]. It has been more than 30 years since the announcement and enforcement of the Act. At the eleventh revision of the Act, an article stipulated that those who violated the control of airguns less viciously could be sentenced to a reduced penalty. However, the penalty of violation of airgun control codes is still extremely severe. Thus domestic courts always ask forensic firearm examiners to test the wounding capability of confiscated airguns to prove they are controlled weapons.

In Taiwan, the official definition of "wounding capability" of guns is that "at the most powerful and appropriate shooting distance, the discharged missile has the kinetic energy capable of perforating human skin." [2] A number of works concerning the terminal ballistics of airgun pellets revealed that the muzzle energy is the major parameter determined the wounding capability of an airgun [3, 4, 5, 6, 7]. In order to correctly evaluate the ability of a discharged missile to perforate human skins, it is critical to determine the energy density or E/a value of a fired missile [8]. This value takes into account not only the mass and velocity of the missile, but also the cross-sectional area. Thus, the muzzle kinetic energy of

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a fired missile is transferred into energy density using the following equations before being used to evaluate the wounding capability of an airgun.

$$E = mv^2/2 \quad (1)$$

$$a = \pi r^2 \quad (2)$$

$$ED = E/a \quad (3)$$

Where E is the kinetic energy, m is the projectile weight, v is the muzzle velocity, a is the cross section area of the projectile, r is the projectile radius.

The energy density (ED) criterion employed by domestic firearms experts to determine the wounding capability of tested firearms is 20.0 J/cm^2 [2, 9].

According to the way that the pellet is propelled, airguns are categorized into three major types. They are: pneumatic type airguns, spring piston airguns, and carbon dioxide (CO_2) airguns. For a multi-pump pneumatic airgun, air is pumped into a high-pressure air reservoir by several pumps of a built-in pump mechanism. A sudden release of high-pressure air from the reservoir provides the power to propel the pellet. Spring-piston airguns are operated by a single stroke of a cocking lever or the barrel to move the piston assembly to compress the spring. Pulling the trigger releases the spring to push the piston forward and compress the air in the chamber to propel the pellet. The high pressure gas obtained from the rapid evaporation of liquid CO_2 is used as the power to propel the pellet in CO_2 airguns. It has been reported that the pressure of CO_2 gas is affected by the variation of ambient temperatures. As a result, the muzzle energy of discharged pellets is also dependent on the temperature variation [9].

Since the muzzle energy determined by firearms examiners is the only forensic evidence used in the court to prove the defendant's guilt of illegal possession of controlled weapons, the reliability of muzzle energy testing procedures should be assured. Thus any parameters that might affect the testing results should be identified and precisely controlled. In order to realize if the muzzle energies of pneumatic and spring piston airguns are also influenced by the fluctuation of ambient temperatures, we conducted a number of test firings using these types of airguns at three different temperature conditions. Basing on the results, we proposed a suggestion that the ambient temperature should be precisely controlled while carrying out the muzzle energy determination of any types of airguns to avoid obtaining controversial results from the same gun by different forensic science labs.

Materials and Methods

Research equipments and materials

1. Chronograph, Chrony Gamma Master (USA).
2. Spring piston air pistol, 4.5 mm caliber, Model HW 45, made in Germany by the H. Weihrauch (Fig.1).
3. Spring piston air rifle, 4.5 mm caliber, Model 800X Winchester air rifle, made in Turkey (Fig.2).
4. Multi-pump pneumatic type air pistol, 4.5 mm caliber, American Classic Model 1377 (Fig.3).
5. Diabolo type pellets (Fig. 4), 4.5 mm diameter, 0.50 g each.

Operation of airguns

For HW 45 spring piston air pistol, the barrel was lifted up to cock the spring-piston assembly and open the breech end of the barrel. After a pellet was inserted into the chamber, the barrel was then pushed down to the locked position to be ready for discharging.

For Winchester Model 800X spring piston air rifle, the barrel was pull downward and to the rear to a solid stop to cock the spring-piston assembly. A pellet was inserted into the chamber at the breech end of the barrel. The barrel was then pulled backward to its original closed and latched position to finish the cocking and loading cycle.

In addition to studying the influence of ambient temperature to the muzzle energy, the effect of pumping times to the muzzle energy was also studied for American Classic Model 1377 multi-pump pneumatic type air pistol. The forearm of the pistol was opened all the way until it stopped and it was then used to pump the air into the air reservoir. At least 3 times but no more than 10 times of pumping was recommended by the owner's manual. But the air pistol was pumped for 2, 3, 5, 7, 10, 12, or 15 strokes before each test firing in this study to thoroughly study the influence of the number of pumping strokes toward the muzzle energy.

Muzzle energy determination

Each of the 4.5 mm caliber airguns mentioned above was used to discharge Diabolo type pellets 4.5 mm in diameter and weighing an average of 0.50 g. The tested airgun was held by the shooter with the barrel being horizontal. The start sensor of the chronograph was placed 1 meter from the muzzle of the test weapon. A cardboard box filled with Kevlar bullet-proof fabrics was placed behind the chronograph to trap the discharged pellets. The sensors of the chronograph were arranged so that they defined planes perpendicular to the line of flight of the pellet. In every test firing the passage of pellet through the start senor turned on the chronograph. The chronograph was shut off by the stop sensor when the pellet passed through it. The muzzle velocity of pass-through pellet was recorded. The energy density of each discharged pellet was calculated as described in the introduction section of this article.

Ambient temperature conditions

Three airguns mentioned above were all tested on three different days in three different seasons of winter, spring, or summer, respectively. The ambient temperatures of testing room on these days were measured to be 15°C, 21.5°C, and 28°C, respectively.

Comparison of muzzle energy

Test firings were repeated for at least three times for each test firing conditions. The muzzle velocity of each test firing was measured, and the muzzle energy density was calculated. The mean value and standard deviation of muzzle energies obtained from each test firing conditions were calculated. A paired Student’s t test was used to establish the significance of differences in muzzle energies between two compared test firing conditions; a confidence level of 95% (p value = 0.05) was chosen for the test.

Fig. 1 The HW 45 spring piston air pistol with the cocking lever opened

Fig. 4 Diabolo type pellets with a caliber of 4.5 mm

Fig. 2 The Winchester Model 800X spring piston air rifle

Fig. 3 The American Classic Model 3177 multi-pump pneumatic type air pistol with the forearm opened

Results and Discussion

HW 45 spring piston type air pistol

The forensic features of the barrel of HW 45 air pistol was firstly observed, measured, and recorded. The results indicated that the HW 45 air pistol has a 4.5 mm caliber rifled barrel with a barrel length of 170 mm. The HW 45 air pistol was then test fired for ten shots each at three different ambient temperature conditions. The muzzle velocities were measured employing chronograph and energies densities of muzzle energies were calculated using equations (1), (2), and (3) mentioned above. The means and standard deviations of muzzle energies of the HW 45 air pistol discharged at 15°C, 21.5°C, and 28°C are also calculated, and they are 39.86 ± 1.39 J/cm^2, 40.01 ± 1.63 J/cm^2, and 41.03 ± 0.91 J/cm^2, respectively. They are all much higher than the wounding capability criterion, 20.0 J/cm^2, employed by domestic courts and forensic scientists. This means that the mere possession of HW 45 air pistol is a criminal violation in Taiwan. The muzzle energies and their means and standard deviations of HW 45 air pistol at different ambient temperatures are shown in Table 1.

Table 1 Muzzle energies, means and standard deviations of HW 45 air pistol test fired at different ambient temperatures, J/cm^2

Ambient temperature	15°C	21.5°C	28°C
Muzzle energy	37.42	36.27	40.14
	38.20	38.84	40.19
	38.74	39.39	40.24
	39.48	39.64	40.24
	39.98	40.34	40.64
	40.24	40.49	41.00
	40.59	40.59	41.35
	40.95	41.05	41.56
	41.04	41.35	42.43
	41.91	42.12	42.54
Mean	39.86	40.01	41.03
Standard deviation	1.39	1.63	0.91

The calculated p values of t test used to establish the significance of differences in muzzle energies at varied temperatures of 15°C vs. 21.5°C, 21.5°C vs. 28°C, and 15°C vs. 28°C, are 0.412, 0.052, and 0.019, respectively. The means of muzzle energies of HW 45 at different ambient temperatures revealed that the muzzle energy of the pistol increased as the ambient temperature elevated. However, only the p value of t test of 15°C vs. 28°C compared pair is smaller than 0.05. This indicated that the difference of muzzle energies is significant only when the difference of ambient temperatures is great enough. In the case of HW 45 air pistol, more than 10°C of temperature difference is required to result in significant difference of muzzle energy when the confidence level of 95% is used. However, it is possible to lead to a significant difference of muzzle energy at 6.5°C temperature difference when the confidence level is reduced to 90%.

Model 800X Winchester spring piston type air rifle

The Model 800X Winchester air rifle has a 4.5 mm caliber rifled barrel with a barrel length of 450 mm. The 800X air rifle was test fired for ten shots each at three different ambient temperature conditions. The muzzle velocities were measured and energies densities of muzzle energies were calculated. The means and standard deviations of muzzle energies of the 800X air rifle fired at 15°C, 21.5°C, and 28°C are also calculated to be 65.24 ± 2.29 J/cm^2, 76.15 ± 1.32 J/cm^2, and 80.87 ± 1.13 J/cm^2, respectively. They are all much higher than the muzzle energies of HW 45 air pistol at corresponding temperatures. Thus the mere possession of 800X air rifle is also a criminal violation in Taiwan. The muzzle energies and their means and standard deviations of Winchester Model 800X air rifle at different ambient temperatures are shown in Table 2.

The p values of t test of the means of muzzle energies at two compared ambient temperatures of 15°C vs. 21.5°C, 21.5°C vs. 28°C, and 15°C vs. 28°C are 6.59 × 10^{-11}, 5.52 × 10^{-8}, and 2.38 × 10^{-11}, respectively. The means of muzzle energies of the Winchester Model 500X air rifle at different ambient temperatures revealed that the muzzle energy of the rifle increased as the ambient temperature elevated. The p value of all tested pair is far smaller than 0.05. This indicated that the difference of muzzle energies is significant when the difference of ambient temperatures is as small as 6.5°C at the confidence level of 95%. The results also revealed that the muzzle energy of 800X air rifle is much higher than that of HW 45 air pistol. And the affect of temperature variation to the muzzle energy of the 800X air rifle is more significant than that of the HW 45 air pistol.

Table 2: Muzzle energies, means and standard deviations of 500X air rifle test fired at different ambient temperatures, J/cm^2

Ambient temperature	15°C	21.5°C	28°C
Muzzle energy	62.56	73.81	79.51
	62.62	75.25	79.65
	63.00	75.39	79.79
	64.01	75.39	80.29
	64.84	75.80	80.64
	64.97	75.87	80.93
	66.19	76.84	81.21
	67.16	77.33	81.57
	68.20	77.82	82.21
	68.86	78.02	82.94
Mean	65.24	76.15	80.87
Standard deviation	2.29	1.32	1.13

American Classic Model 1377 multi-pump pneumatic type air pistol

The American Classic Model 1377 air pistol employed in this study has a 4.5 mm caliber smooth-bored barrel with a barrel length of 260 mm. During the first set of test firings the air reservoir was initially pumped for only a single stroke. This resulted in the failing of discharging the pellet loaded in the chamber. So the American Classic Model 1377 air pistol was pumped for at least two strokes before each test firing in the following experiments. Three shots were fired for each test firing conditions with varied strokes of pumping at three different ambient temperatures. The muzzle energies and their means and standard deviations of American Classic Model 1377 air pistol with varied strokes of pumping at 15°C, 21.5°C, and 28°C are shown in Table 3, 4, and 5, respectively.

It is obvious that the muzzle energy of the American Classic Model 1377 air pistol rapidly increased as the pumping strokes was increased from 2 strokes to10 strokes at any tested ambient temperatures. The increase of muzzle energy became slower after 10 strokes of pumping. This tendency is shown in Fig. 5, 6, and 7. The results proved that the muzzle energy of the pneumatic type airgun was affected by the number of pumping strokes.

Table 3: Muzzle energies, means and standard deviations of the American Classic Model 1377 air pistol with varied strokes of pumping at 15°C, J/cm^2

Pumping times	Muzzle energy	Mean	Standard deviation
2 strokes	7.98 9.03 9.39	8.80	0.73
3 strokes	14.23 14.36 14.74	14.44	0.27
5 strokes	21.74 21.76 22.22	21.91	0.27
7 strokes	27.35 27.56 27.56	27.49	0.12
10 strokes	30.06 30.80 31.78	30.88	0.86
12 strokes	34.38 34.71 35.09	34.73	0.36
15 strokes	37.09 37.57 37.62	37.43	0.29

Table 4: Muzzle energies, means and standard deviations of the American Classic Model 1377 air pistol with varied strokes of pumping at 21.5°C, J/cm^2

Pumping times	Muzzle energy	Mean	Standard deviation
2 strokes	9.9 10 10.09	10.00	0.10
3 strokes	15.78 15.94 15.97	15.90	0.10
5 strokes	23.78 23.82 23.86	23.82	0.04

	28.73		
7 strokes	28.78	28.83	0.14
	28.99		
	34.62		
10 strokes	34.99	35.07	0.49
	35.60		
	36.22		
12 strokes	37.09	36.83	0.53
	37.18		
	39.44		
15 strokes	39.74	39.59	0.15
	39.59		

Table 5: Muzzle energies, means and standard deviations of the American Classic Model 1377 air pistol with varied strokes of pumping at 28°C, J/cm^2

Pumping times	Muzzle energy	Mean	Standard deviation
	10.38		
2 strokes	10.58	10.63	0.28
	10.93		
	16.03		
3 strokes	16.23	16.16	0.12
	16.23		
	23.89		
5 strokes	24.05	24.04	0.14
	24.17		
	29.33		
7 strokes	29.46	29.52	0.22
	29.76		
	35.89		
10 strokes	36.08	36.02	0.11
	36.08		
	38.11		
12 strokes	38.35	38.30	0.17
	38.45		
	39.69		
15 strokes	39.94	39.92	0.23
	40.14		

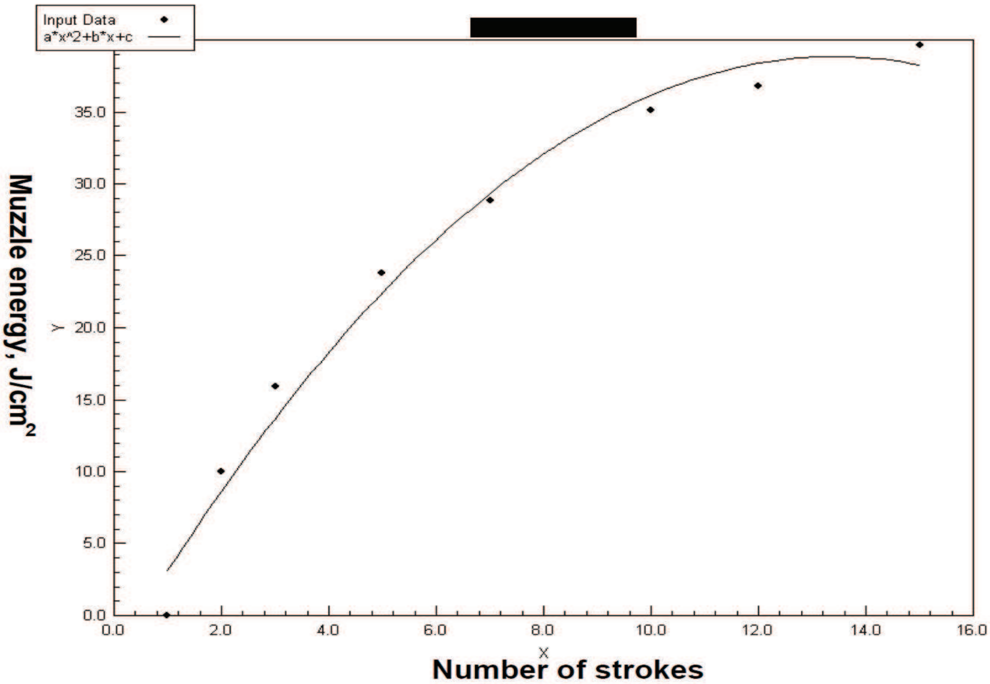

Fig. 5 The increase of muzzle energy with the increase of pumping strokes at 15°C

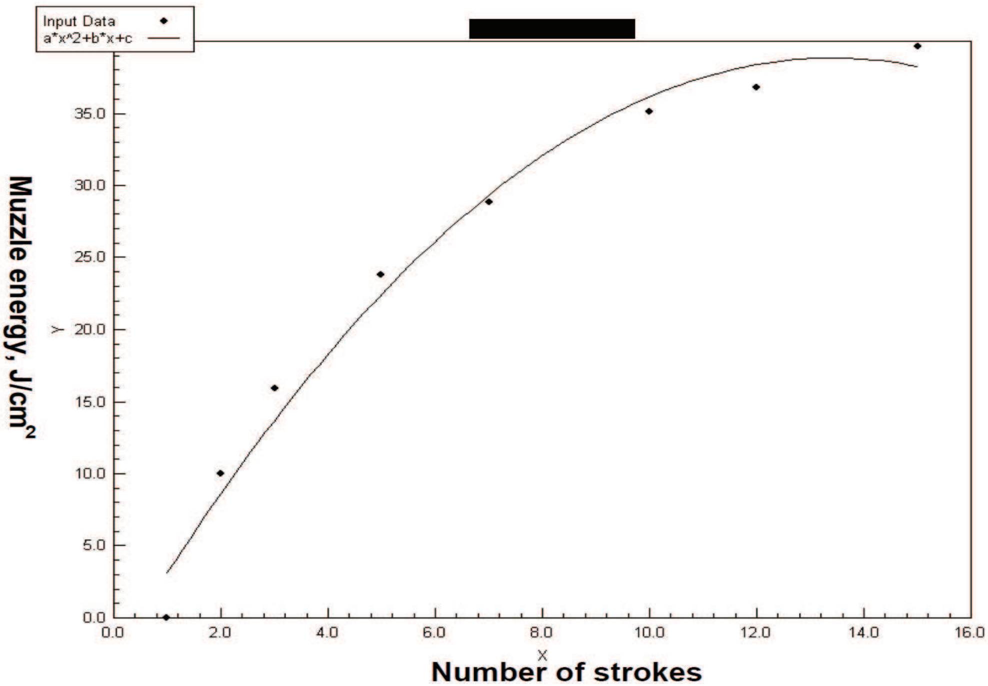

Fig. 6 The increase of muzzle energy with the increase of pumping strokes at 21.5°C

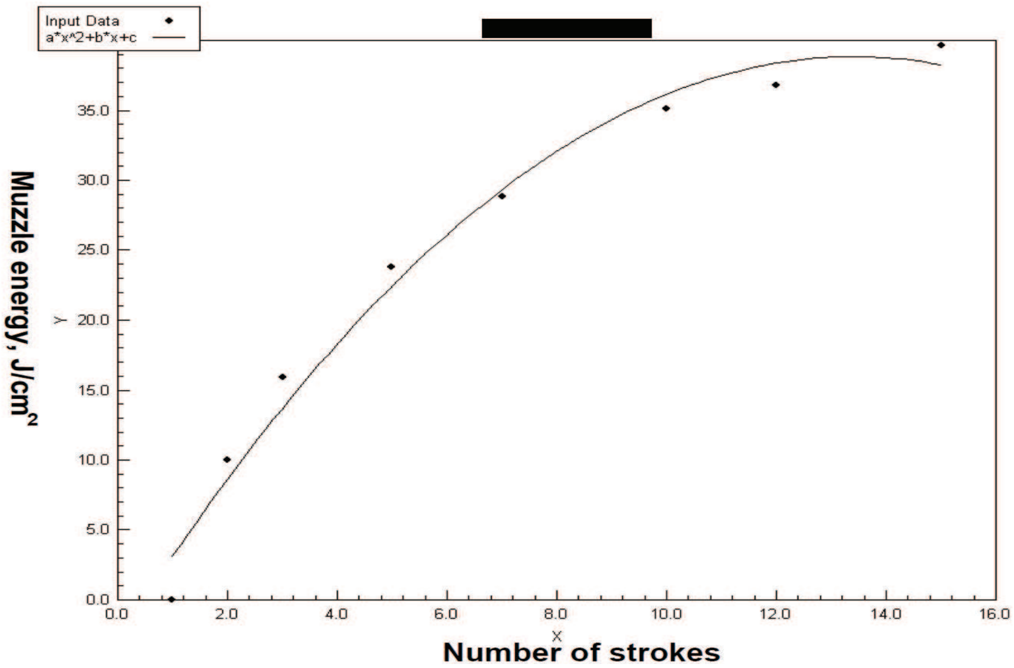

Fig. 7 The increase of muzzle energy with the increase of pumping strokes at 28°C

The results also indicated that the muzzle energy of the American Classic Model 1377 air pistol was higher than the wounding capability criterion only when the pistol was pumped for more than 4 strokes. So care must be taken to pump the air reservoirs for enough strokes while conducting the wounding capability determination of the pneumatic type airguns to avoid inaccurate testing results.

The p values of t test of means of muzzle energies of Classic Model 1377 air pistol at compared ambient temperatures of 15°C vs. 21.5°C, 21.5°C vs. 28°C, and 15°C vs. 28°C with varied strokes of pumping times are shown in Table 6. All of the p values of compared temperatures with varied pumping times are smaller than 0.05. This means that the elevation of ambient temperature results in the significant increase of muzzle energy of a multi-pump pneumatic type air pistol.

Table 6 :The *t* test results of means of muzzle energies of Classic Model 1377 air pistol at compared ambient temperatures with varied pumping times.

Pumping times	p values of *t* test of means of muzzle energies		
	15°C vs. 21.5°C	21.5°C vs. 28°C	15°C vs. 28°C
2 strokes	0.024	0.010	0.008
3 strokes	0.0004	0.020	0.0003
5 strokes	0.0001	0.030	0.0001
7 strokes	0.0001	0.005	7.66×10^{-5}
10 strokes	0.0009	0.016	0.0003
12 strokes	0.002	0.005	4.87×10^{-5}
15 strokes	0.0002	0.049	0.0002

Conclusions

The results of this study revealed that the muzzle energies of not only the carbon dioxide airguns but also the spring piston and pneumatic type airguns were significantly affected by the variation of ambient temperatures. Test firing results indicated that the muzzle energy of an airgun increased as the ambient temperature elevated. A paired Student's t test indicated that the difference of muzzle energies is significant only when the temperature difference is great enough. Thus, in order to obtain accurate and consistent wounding capability test results within the same lab in different seasons or between different labs located at varied latitudes, the temperatures of the testing rooms should be well controlled.

The results also indicated that there was significant muzzle energy difference between firings with different strokes of pumping while a multi-pump pneumatic airgun was fired. So the muzzle energies of a multi-pump pneumatic airgun under varied strokes of pumping should be thoroughly investigated before the conclusion of wounding capability test was reached.

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