

Effect of popper condition and mass on the energy and maximum height of poppers

Lorenzo Brunie, Jacob Kadan,* Ethan Sobel, and Tarun Ramesh

Science & Engineering Magnet Program, *Manalapan High School, Englishtown, NJ 07726 USA*

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Poppers are inexpensive toys consisting of a ball and spring that are able to jump; each popper has an emoji design on its face. Using poppers as a model system to examine energy conservation, this experiment investigated how their mass and design/condition affected their maximum height and total mechanical energy. We examined two poppers, differentiated by mass and design/condition (5.50 g happy vs 5.40 g sad), and ran multiple trials. We recorded the maximum height and initial velocity using video kinematics. We found that the heavier, happy popper consistently reached greater heights and had a higher initial velocity and total energy than the lighter, sad popper. Due to previous usage, mechanical warping would occur in the sad popper, illustrating the effect of the specimen’s material condition on performance. We believe that specimen condition, i.e. from previous usage, is the primary factor influencing mechanical energy output rather than mass alone or emoji design, but concede our experimental design is unable to conclusively test between these alternatives.

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I. INTRODUCTION

When an object is launched directly upwards, its energy gradually converts from kinetic to gravitational potential energy until the object reaches its maximum height. At this maximum height, the object then experiences a temporary state of rest, where the kinetic energy is fully converted to potential energy. The object then begins to drop towards the ground due to gravity, where the energy is converted into other forms of energy, like acoustic or thermal. We used the Law of Conservation of Energy [1–3], which states that energy cannot be created or destroyed but only transformed from one form to another, to compare the work done in compressing a spring with kinetic and gravitational potential energy as the spring launches and reaches its maximum height. Kinetic and gravitational potential energy were estimated from kinematics data obtained using Tracker Online [4] and methods similar to [5–10].

Poppers (Liberty Imports “Jumping Gens”; Allentown, PA) are inexpensive toys consisting of a ethylene vinyl acetate (EVA) foam ball and spring that are able to jump; each popper has an emoji design on its face. Using poppers as a model system to examine energy conservation, this experiment investigated how their mass and design/condition affected their maximum height and total mechanical energy. We examined two poppers, differentiated by mass and design/condition (5.50 g happy vs 5.40 g sad), and ran multiple trials to determine total mechanical energy and conversion efficiency. By compar-

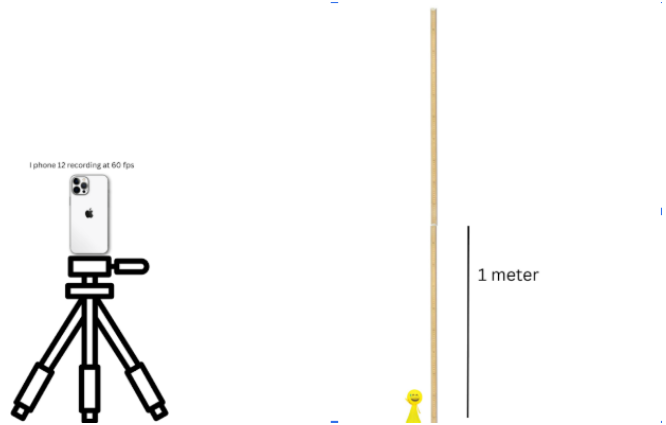


FIG. 1. Initial setup for data collection showing popper, two meter sticks, and iPhone 12 on a tripod, recording at 60 frame/s.

ing 5 trials per popper, we used statistical analysis to determine whether the observed variations in the data were significant or attributable to experimental error.

We hypothesized that previous usage of the popper, rather than the mass alone, would act as the primary factor determining launch velocities and max heights.

II. METHODS AND MATERIALS

A. Objects launched

As shown in Fig. 1, to measure the height (y), both sets of poppers were launched. We used two meter sticks, taped to the wall at regular intervals, stacked on top of each other, with the first touching the ground and the second directly on top of the first. The purpose of the verbal countdown before each trial was to synchronize the

* Contact author: 427jkadan@frhsd.com

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popper’s release and the start of the video recording. An iPhone 12 (Apple; Cupertino, CA) was utilized to record each launch at 60 frame/s. Before the launch, the poppers’ masses were recorded. The objects were released from rest at the moment the countdown reached zero, without any initial lift upwards. Each type of popper (happy, sad) was launched five times. We used frame-by-frame analysis with Tracker Online [4] to record the poppers’ highest points and initial velocities.

B. Work and energy input

To determine the work done on the popper, the force and vertical displacement of the center was measured during compression. The popper was placed on a digital scale (TOP2KG; Smart Weigh; Jiangsu, China) and a scissor jack was used to controllably compress the popper by 0.005 m increments. Force was converted from indicated mass readings in g to N using $F = mg$, where $g = 9.8 \text{ m s}^{-2}$ [1–3].

The work was then calculated by using a trapezoidal method to numerically integrate as follows [1, 11]:

$$W = \int_0^{x_{max}} F dx. \quad (1)$$

This value represents both the work done in compressing the popper (W) and the total Elastic Potential Energy (EPE) stored in the popper before launch. This may have caused some data variations due to human error and the difficulty of perfectly centering the popper. We then tabulate the efficiency of the launch process as

$$\eta = \frac{\text{mechanical energy output}}{\text{work input}} \times 100\%. \quad (2)$$

C. Null and alternative hypotheses

We hypothesized that the emoji design should have no real impact on launch velocity or maximum height, thus the two popper designs should have equal mean launch velocities and maximum heights (H_0). Alternatively, the two popper designs could have different mean launch velocities and maximum heights (H_a).

The graphical emoji design should have negligible impact on the device performance, but confounding effects could be the mass or the usage history and physical condition of an individual popper. In retrospect, we recognize that testing a single specimen each of happy versus sad left us unable to conclusively determine whether observed differences are due to the emoji design or due to individual effects.

Data and code are available at <https://github.com/devangel77b/427jkadan-lab3>.

TABLE I. Sad popper initial velocity and height data for $n = 5$ replicates. $m = 0.00540 \text{ kg}$, $v_0 = 4.65 \pm 0.05 \text{ m s}^{-1}$, $h = 1.26 \pm 0.03 \text{ m}$, $\text{KE} = 0.058 \pm 0.001 \text{ J}$ and $\text{GPE} = 0.067 \pm 0.002 \text{ J}$.

trial	$v_0, \text{ m s}^{-1}$	$h, \text{ m}$
1	4.60	1.23
2	4.65	1.24
3	4.72	1.28
4	4.68	1.30
5	4.60	1.25

TABLE II. Happy popper initial velocity and height data for $n = 5$ replicates. $m = 0.00550 \text{ kg}$, $v_0 = 5.46 \pm 0.04 \text{ m s}^{-1}$, $h = 1.50 \pm 0.02 \text{ m}$, $\text{KE} = 0.082 \pm 0.001 \text{ J}$ and $\text{GPE} = 0.081 \pm 0.001 \text{ J}$.

trial	$v_0, \text{ m s}^{-1}$	$h, \text{ m}$
1	5.45	1.48
2	5.42	1.48
3	5.48	1.50
4	5.44	1.49
5	5.46	1.53

III. RESULTS

Tables I and II summarize the initial velocity and maximum height for sad and happy popper launches, respectively.

The data from Tables I and II are summarized in Fig. 2, which shows differences between happy and sad popper performance are significant (ANOVA; $p = 2.27 \times 10^{-9}$). Sad popper jumps had lower initial velocities and lower maximum heights.

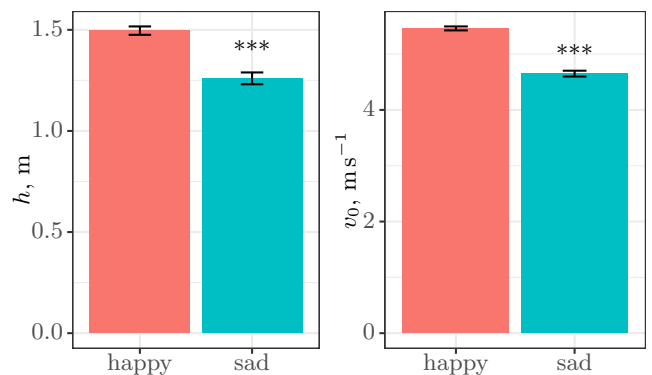


FIG. 2. Initial velocity (v_0) and height (h) data. Data from Tables I and II. For both h (ANOVA; $p = 4.39 \times 10^{-7}$) and v_0 (ANOVA; $p = 2.27 \times 10^{-9}$), differences between happy and sad poppers are significant.

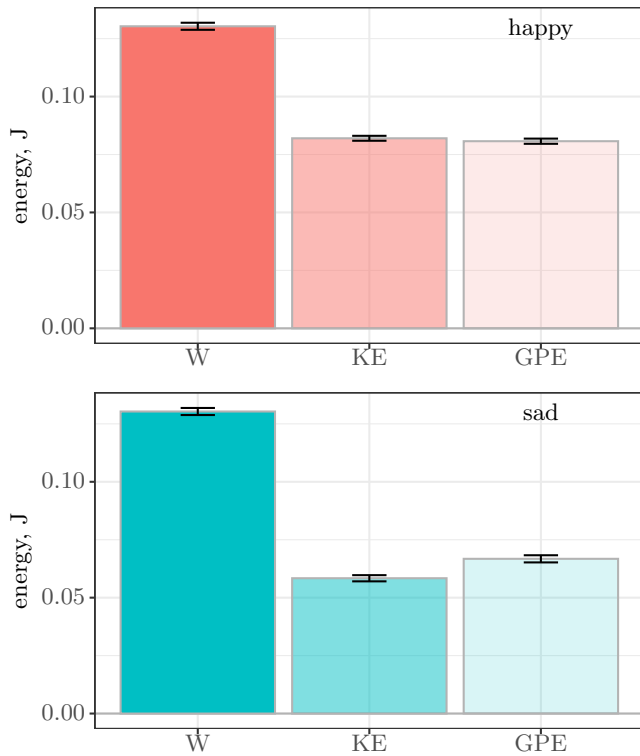


FIG. 3. Comparative energy profiles of happy (top) versus sad (bottom) poppers.

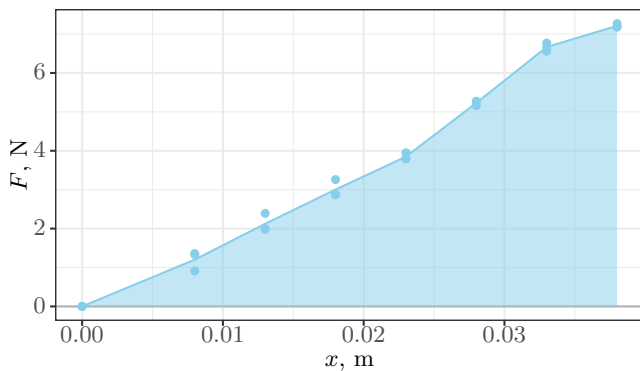


FIG. 4. Force versus displacement. The work done in compressing the popper (shaded area) is $W = 0.130 \pm 0.001$ J.

Comparison of the work done to compress (W), initial kinetic energy (KE) and maximum gravitational potential energy (GPE) are shown in Fig. 3.

The work done in compressing the popper is shown in detail in Fig. 4. At full compression, the work to compress a popper was 0.130 ± 0.001 J.

IV. DISCUSSION

A. Analysis of mass and performance

The results of this experiment indicated that the happy popper had higher maximum heights, higher initial velocities, and greater mechanical energy than the sad popper. As seen in Fig. 2, the happy popper reached an average height of 1.50 m, while the sad popper reached an average of 1.26 m. Additionally, the average initial velocity for the happy popper was 5.46 m s^{-1} , compared to 4.65 m s^{-1} for the sad popper (Fig. 2).

One possibility is that there is an actual effect from the different designs, happy versus sad. Alternatively, the findings may be the result of the 0.1 g mass difference between the two specimens tested. A third possible explanation for these results is the condition of the poppers at launch. If the happy popper was fresh out of the box while the sad popper was previously used, any previous launches of the sad popper could have resulted in plastic deformation of the EVA elastomer material, leading to lower maximum heights, low initial velocity, and lower mechanical energy. As our design of experiment only tested a single specimen each of happy versus sad popper, we are unable to further narrow down between these alternatives.

B. Energy efficiency and dissipation

By comparing the total mechanical energy to the calculated work to compress the poppers (Fig. 3), we see that the popper launch process was approximately 46% to 63% efficient. These efficiencies appear reasonable considering the coefficient of restitution and hysteresis of EVA foam rubber and other plastic materials, the possibility of friction in the spring section of the poppers, snap-through instability during launch. Furthermore, the relative agreement of KE and GPE in Fig. 3 suggests that air drag and losses during the flight phase are small compared to energy losses during the launch process. These observations are also in line with those reported by others in this same issue.

C. Statistical significance and experimental variables

The test confirms the statistical significance of deviations in mean initial velocity, maximum height, and launch velocity. The t -statistic of 28.9 is above the critical t -value of 2.306 for 8 degrees of freedom at $\alpha = 0.05$. We reject the null hypothesis that the two poppers have the same mean initial velocity, maximum height, and launch velocities since the p -value is significantly smaller than $\alpha = 0.05$.

Since both poppers were likely made from identical molds and materials, we feel the energy gap is best ex-

plained by prior use. If the sad popper were extensively used before testing, so that its resilience and overall structure were degraded, these would explain the observations in a way that is more convincing that the emoji design, which should have no effect, or the small mass difference due to manufacturing tolerances.

Our experimental design only used one specimen of each of happy versus sad popper designs and did not control for prior use, thus we cannot draw a definitive conclusion without further testing. We recommend using multiple specimens of each, and ensuring that they are drawn from a fresh, plastic-wrapped and sealed new box. Any future experiments should control for the popper

condition by using brand-new poppers with varying mass or by measuring the spring constant (K) beforehand.

V. ACKNOWLEDGEMENTS

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