ELSEVIER

Applied Ergonomics 37 (2006) 113–118

APPLIED ERGONOMICS

www.elsevier.com/locate/apergo

Influence of hand grenade weight, shape and diameter on performance and subjective handling properties in relations to ergonomic design considerations

Cheng-Kang Yuan[a,*], Cheng-Lang Kuo[b]

[a]*Department of Business Administration, Lunghwa University of Science & Technology, Taiwan, ROC*
[b]*Department of Industry Management, China Institute of Technology, Taiwan, ROC*

Received 8 September 2004; accepted 20 June 2005

Abstract

Three hand-grenade design factors, namely shape (ball, oval, can), diameter (55, 60, and 65 mm) and weight (300, 400, and 500 g), were assessed. The objective criteria were (1) throwing distance from the grenade stop point to throwing point, and (2) error distance from the grenade stop point to the target. The subjective criteria were (3) the overall rating of handling (to hold and control) properties and (4) the rating of perceived exertions of throwing strength. Twenty ROC Army soldiers threw a Mark II practice grenade to familiarize them with the throwing procedure, and then, while standing, threw 21 experimental, mockup grenades at a target indicated by a flagpole 40 m away from the throwing point. Grenade weight had the greatest effect on both subjective and objective criteria. The 300 g grenade had the greatest throwing distance (38.6 ± 6.5 m) and had the greatest accuracy (6.9 ± 3.9 m). Grenade shape was also a significant influence based on both the subjective and objective criteria; with the ball shape being the best. Grenade diameter, within the range tested, did not affect either the subjective or objective criteria.

1. Introduction

The hand grenade is an easy-to-deploy but somewhat inaccurate small thrown bomb. The thrower must use their own strength to throw the hand grenade sufficiently far to damage the target while simultaneously avoiding the risk of self-damage associated with the large lethal radius (generally 10–20 m). These inherently erratic characteristics make the hand grenade a "pretty inappropriate weapon that is dangerous to an attacker and deadly for its victims." (Morris, 2002).

Many new grenade designs have emerged from the armament industries. The designs of current fragmentation grenades vary, but can be categorized based on three design features: shape, weight, and diameter. Grenade shape is typically categorized as one of spherical, oval, or can. Grenade weights range from 180 g (Austria HG 86 Mini) to 765 g (Pakistan No.36M Mk.I). Meanwhile, grenade diameters range from 43 mm (Austria HG 86 Mini) to 82 mm (France LU213) (Lynn, 2002).

Many reports exist regarding injuries or even stress fractures of the upper limb involving throwing movement (Chao et al., 1971; Barker and Barker, 1997; Brukner, 1998; Jones and Knapik, 1999; Reinold et al., 2000). However, the influence of grenade design on throwing performance and the handling properties is little studied, and the old-fashioned Mark II hand grenade continues to be used in numerous militaries around the world, including the Army of the Republic of China (ROC). However, because of the heavy weight (~610 g) of the Mark II grenade, many ROC soldiers have difficulty throwing this grenade a full 40 m, and

*Corresponding author. Tel.: +886 2 8209 3211x6502; fax: +886 2 8209 3211x6510.
E-mail addresses: bxy@mail.lhu.edu.tw (C.-K. Yuan), kcl@cc.chit.edu.tw (C.-L. Kuo).

0003-6870/$ - see front matter
doi:10.1016/j.apergo.2005.06.008

some have even suffered serious upper limb stress fractures during throw training (Kao, 1999). Based on the main functional requirements of hand grenades, military training doctrines generally require 30–50 m throwing distance and 1–5 m throwing precision (Kao, 1999). The article of "The theory and practice of hand grenades" (MILTECH, 2002) clearly stated "In general, a well-trained soldier is expected to throw a standard fragmentation grenade to a range of 30 m, with 40 m being close to the limit." The Millennium's End Rulebook (2005) devised some simple rules for throwing grenades and other lobbed objects, which stating:

- An average soldier can throw an M-67 grenade weighing 250 g to a distance of 40 m.
- An average soldier can throw a 250 g grenade sized object a distance in meters equal to their strength (not specified what and how to measure).
- For every 250 g above the base 250 g, the maximum throwing distance is reduced by 5 m.

Clearly, these generalizations regarding grenade throwing distance focus primarily on grenade weight and thrower strength. In addition to throwing distance, throwing precision (accuracy) is also an important but frequently overlooked feature of grenade design. Owing to the rounded shape and thrown delivery of a hand grenade, it will usually not explode upon hitting the ground (except when an impact fuse is used). Instead, the grenade will roll away from the impact point—unless it falls into a confined area like a foxhole, window, or trench. For open ground targets, a throwing precision of 1–5 m is adequate, since the 10–15 m damage radius of general fragmentation hand grenades will exceed the loss of accuracy associated with roll-away.

Concerns regarding the design, training doctrine and safety of the Mark II grenade inspired this investigation. This work was sponsored by the National Science Council of ROC to assess the ergonomic issues related to hand grenade designs and to understand the influence of grenade design on handling properties and throwing performance, and determining the appropriate weight range for hand throwing grenades.

2. Methods

2.1. Subjects

Twenty male ROC Army infantry soldiers were recruited from the Armament Test Field of the Armaments Bureau as volunteer subjects. Subjects were all capable to throw a Mark II practice grenade at least 30 m during their boot camp training. However, because of irregular training practice during their service, these subjects were not considered skillful grenade throwers, but rather average throwers who had completed basic training. Subjects were briefed on the purpose, procedures, and potential hazards of the field test, then read and signed a voluntary agreement of informed consent before taking the test. The field test and use of human subjects adhered to the standards of the National Science Council, and was approved by the Armaments Bureau.

2.2. Experiment designs

To identify the main influences on hand grenade handling properties and throwing performance, this investigation isolated the three ergonomic related design factors of shape, weight, and diameter based on modern hand grenade designs (Combat grenades–hand, 2000). Each design factor was tested by three experimental levels also based on modern hand grenade designs to determine its effect on handling properties and throwing performance.

The original experiment involved a complete 3^3 factorial design. However, to prevent possible fatigue or even injuries from repeated throwing (the subjects were required to make 27 throws), this investigation simplified the test by removing six experiment cells, including the smallest 55 mm diameter ball shape and the largest 65 mm diameter can shape grenades. The result was an incomplete 3^3 factorial design involving 21 test mockups, as listed in Table 1. The smooth skin (without pins, handles, or other extrusions) lathed aluminum grenades mockups were custom-made only for the experiment purpose according to the experimental setting. For example, the three 60 mm diameter, ball shape mockups were made by hollowing the inner body tuned to the three weight setting. The Mark II practice grenade (oval shape, 610 g, and 60 mm in diameter) was also test thrown in this investigation to provide a comparison for the tested grenade mockups.

Table 1
Experimental design and grenade mockups tested in this study

Shape	Weight (g)	Diameter		
		55 mm	60 mm	65 mm
Ball	300	—	7	16
	400	—	8	17
	500	—	9	18
Oval	300	1	10	19
	400	2	11	20
	500	3	12	21
Can	300	4	13	—
	400	5	14	—
	500	6	15	—

—: cells not tested in this study.