Dynamics of spear throwing

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(Received 22 April 2002; accepted 1 November 2002)

The spear thrower (atlatl) is a hunting weapon with very ancient origins. It is a lever that enables wrist rotation to make a substantial increase in the velocity of a thrown spear. A model for throwing a projectile with an atlatl is presented. This model is used to analyze the projectile velocity as a function of the dimensions, rigidity, and mass distribution of the atlatl and mass of the projectile. The model assumes that the throwing force and wrist torque are functions only of the horizontal position of the throwing hand and that the spear is sufficiently long that the atlatl applies only a horizontal force to the proximal end of the spear. The applied force and torque were derived from a high-speed video digitizer plus the known physical dimensions of the atlatl and spear.
[DOI: 10.1119/1.1533055]

I. INTRODUCTION

A spear thrower enabled a stone age hunter to throw a light weight spear with greater velocity than could be obtained by hand. It consisted of a lever from 0.3 to 1.0 m long with a handgrip at one end, and a spur at the far end that engages the proximal end of the spear. In Europe the spear was definitely used in the Magdelanian period (10 000–16 000 years ago) and possibly in the Solutrean (16 000–20 000 years ago). North American spear throwers have been dated at 8000 years. In Australia the spear thrower is popularly called a woomera, one of the many Aboriginal names for a spear thrower. In the nomenclature of North American archaeology the spear thrower is called an *atlatl*, a Mexican word, and the projectile is called a dart, terms that will be used in the remainder of this paper.

Atlatls were still used in the mid-twentieth century by Native Alaskans in pursuit of marine mammals and by Australian Aboriginal hunters. There has also been a resurgence of interest in atlatl marksmanship among people who are trying to relearn the skills of our stone age ancestors. The World Atlatl Association[1] holds tournaments throughout North America and Europe. Pet stores sell a "Chuckit" for throwing tennis balls to a dog.[2] This device, which works on the same principles as the atlatl, allows users to throw the ball much farther and to keep the canine saliva off their hand.

The operating principles of the atlatl are very simple. Wrist torque applied to the length of the atlatl allows wrist rotation to increase the velocity of the dart. For maximum velocity the length of the atlatl depends on the mass of the dart.

II. OBJECTIVE

The main objective of this paper is to determine the relation between the dart velocity and the dimensions and weight distribution of the atlatl. Implicit in the analysis is the assumption that exactly the same human effort is used in all throws. The variation in velocity is due entirely to differences in the mass of the dart and the dimensions and weight distribution of the atlatl. A simple computer model for the process of throwing is developed. The model is sufficiently general so that it can be used to predict the velocity of a dart with arbitrary mass when thrown either by hand or with an atlatl of arbitrary dimensions. Two of the input parameters for the model, the horizontal force and wrist torque versus hand position, are derived from a high-speed video digitized recording of a person throwing a dart with an atlatl. The human effort (horizontal force and wrist torque versus hand position) is derived from a high-speed video digitizer record of a person throwing a dart with an atlatl. The other two parameters are the mass of the throwing hand and its radius of gyration. The results of applying the model to darts and atlatls of different dimensions are presented.

A model was used because a human being cannot be expected to throw with exactly the same effort time after time. In Ref. 3 experiments were done to measure the maximum distance achieved in throwing an atlatl dart. Ten throws ranged from 46.5 to 55.9 m with a mean distance thrown of 51.3 m. In Ref. 4 experiments with a weighted atlatl and one sequence of six throws achieved a mean distance of 42.6 m (140 ft) with a range of 30.5 to 54.9 m. Detailed comparative measurements of the distance thrown with an atlatl with and without an added weight were done in Ref. 5. The mean and standard deviation of the distance of 30 throws were typically 66.5 and 4.9 m. The dart velocity was measured with a radar speed gun and with a high-speed movie camera plus image digitizer. In a typical experimental run the mean dart velocity and standard deviation were 25.33 and 1.67 m/s, respectively. A different experiment yielded a mean velocity and standard deviation of 20.73 and 0.99 m/s, respectively. These experiments show that it is impossible to make identical throws even with the same atlatl and dart. To make an accurate assessment of atlatl performance, we must assume that the physical effort applied by the thrower is constant. Otherwise, the atlatl that gives the best velocity might just be the throw when the thrower was the least tired.

III. THE ACT OF THROWING

Making a horizontal throw from a standing position involves many muscles and joints. To estimate performance, I have reduced the act of throwing to four physical parameters, a horizontal force, a wrist torque, the hand mass, and the hand radius of gyration. The horizontal force is assumed to be a function only of the horizontal position of the hand. Any dependence of the force on the speed of rotation of joints is ignored. This assumption is equivalent to saying that the contracting force of the muscles is independent of their contraction speed in the range of interest. An analysis of the experi-