ABSTRACT

STICKS AND STONES MAY BREAK MY BONES:
COMPARATIVE EFFECTIVENESS AND LEARNING TIMES
IN PREHISTORIC FORCE MULTIPLIER WEAPONS

Kathryn Sian DeWitt, M.A.
Department of Anthropology
Northern Illinois University, 2013
Mark Mehrer, Director

In the course of the development of weaponry and technology, the issue of whether a novice would be able to learn to use a new force multiplier quickly and accurately enough to benefit from its use is in question here. In the case of the atlatl and the sling, two force multiplier weapons that have existed for thousands of years, which would a novice be able to more effectively use in a brief amount of time, and what would this tell archaeologists about the behaviors surrounding each weapon? While the results of several volunteers learning how to use both the sling and the atlatl were unexpected, and indicate far more than an outright beginning advantage over throwing their ammunition of choice in their initial adoption and development, the outcome of their introduction to these weapons can be understood in the larger context of how human technology and weaponry developed.

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IN PREHISTORIC FORCE MULTIPLIER WEAPONS

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KATHRYN SIAN DEWITT

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CHAPTER #1: INTRODUCTION

Two weapons, the atlatl and the sling, have histories that stretch far into prehistoric times in multiple places around the world and have even survived in several forms and uses into the modern world, kept from extinction by enthusiasts (Fogelman, 1997; Savage, 1999), archaeologists, and survivalists in need of expedient hunting and combat weapons (Pewtherer, 2010). Studying both weapons in depth may help shed new light on the cultural and gender issues in their development and use, the ecology of their use, their place in the history of weapons technology, and, if extended to include forensic anthropology, could track their use across cultures, time, and potentially species even when the weapons themselves cannot be found.

Both are force multiplier weapons, meaning that they vastly multiply any exerted “input” force into “output” force beyond what a human arm could exert unaided. But the records of their longevity and their effectiveness do not account for their popularity around the world. How quickly would a novice beginner with no prior experience with either weapon have learned the necessary skills to acquire useful range and accuracy? What advantages would mastery of the weapon have conferred on its user? Considering the inherent features of the two weapons, the atlatl is hypothesized to have been quicker to master and more accurate than the sling. The sling is hypothesized to have a greater effective range.

The atlatl appeared as a separate invention at different times throughout the Arctic, the Americas, Europe, and Australia. Likewise, the sling was an independent invention in

Oceania, the Americas, Asia, and Europe with a particular concentration in the Mediterranean region. Because of this, the weapons warrant closer attention.

The atlatl does not have as extensive a military history as the sling. It saw wartime use in several Central and South American civilizations (Fogelman, 1997; Nuttal, 1891) but is primarily considered a hunting weapon by archaeologists and modern users. Modern archaeologists have experimented with the system, initially to understand how effective of a weapon it would have been (Browne, 1940) and later to see if some of its mythical abilities, such as piercing plate armor, were true (Whittaker, 2009) or if different variables such as the flexibility of the atlatl made a difference during its use (Whittaker & Maginniss, 2006).

The sling appears to have served equally as a hunting or personal defense weapon (Dohrenwend, 2002; Harrison, 2006; Savage, 1999) and as a standard military weapon until the advent of mass-produced accurate firearms (Dohrenwend, 2002; Harrison, 2006: Korfmann, 1973). Today, it sees use in violent protests and street combat throughout the world (Gettleman, 2008; Savage, 1999). Although sling ammunition is a common find in fortifications and battlefields around the world (Arkush, 2008; Greep, 1987), archaeological analysis of the sling itself has been limited to historical texts and battlefield records, rather than experimental studies like those of the atlatl.

The following experiment generated data on how beginners learn to use force multipliers. The hypotheses of this experiment are that, if a volunteer picked up both weapons with no prior experience with either and devoted the same amount of practice to each:

1) The atlatl would be mastered more quickly than the sling, as measured by composite scores and practice time.

2) The atlatl would be a more accurate weapon than the sling.

3) The sling would have a longer effective range than the atlatl.

These hypotheses were tested with the assistance of several adult volunteers who had no prior experience with either weapon.

CHAPTER #2: THEORY

This study is an instance of experimental archaeology, which occupies a subset of archaeology's middle-range theory. Middle-range theory is a processual approach that relies on objective scientific data to connect ancient behavior to the modern archaeological record (Tschauner, 1996). Middle-range theory often relies on observation or participant observation to collect data. Similarly, experimental archaeology, in its turn, conducts experiments in a very scientific manner, using testable hypotheses and repeatable experiments to collect data and generate further hypotheses (Outram, 2008).

Lewis Binford took a middle-range approach to understanding hunting camp site structure (Binford, 1978). Binford followed a hunting group for several months, noting where they sat when in camp relative to the fire, wind direction, and discard areas; where they worked; and where they were likely to lose small objects. From this, he modeled what a prehistoric hunting camp was likely to look like to archaeologists (Binford, 1978). The result is an interpretive model based on known modern behaviors that can be used to generate hypotheses to be tested against data from archaeological sites.

Other middle-range archaeologists and their approaches to their own specializations have included Bettinger (1987), who offers middle-range theory as a way of testing theories regarding hunter-gatherer groups to be tested at hunter-gatherer sites, and Torrence (1986) in her analysis of the manufacture and trade of lithic tools around the Aegean and how the differing manufacturing techniques may have indicated different trades. Pierce (1989) critiqued middle-range theory because it relies heavily on generalizations of behavior that may be faulty and because descriptions of the behavior and of the site itself rely on assumptions that may be incorrect, calling the empirical approach into question. Still, the middle-range approach can shed light on past behaviors, even if initial assumptions are incorrect. When inspired by new hypotheses generated from modern observations, archaeological investigation can offer insights into behaviors that are otherwise not available.

Experimental archaeology attempts to replicate artifacts, behaviors, and features as they might have been used by people in the past using scientific methodology (Coles, 1979; Ferguson, 2010; Seetah, 2008). Thus, experimental archaeology emphasizes a scientific approach to archaeology by creating replicable experiments and collecting data rather than relying on participant observation, as with ethnoarchaeology. As in other sciences, the experiment has a hypothesis that can be supported or disproven through testing, and the experiment itself is replicable and controls well-defined variables. This is unlike living history or historical reenactment, which relies on archaeological findings to simply reproduce sites, events, or behaviors but does not make discoveries or test hypotheses. Experimental archaeology is a way of scientifically testing hypotheses that are generated by archaeological finds.

While such “laboratory” experiments do not conclusively prove what may have occurred in the past, they suggest possibilities and do provide insight for further interpretation. An experimental archaeologist might create a new house, burn it to the ground, and allow it to rot, then excavate it to see how those processes affected the resulting archaeological record and how they might differ from a house that was simply abandoned. Various experiments with lithic cut-mark data on zoological remains fall into this category

(Seetah, 2008). Another approach in experimental archaeology uses the findings of a particular site to guide the archaeologists’ attempts to replicate or test the validity of a theory about the behavior involved in a site, activity, or artifact. Sometimes these experiments yield new insights about the behavior, technology, and lives of ancient peoples. Such is the case of flintknapping as a reconstruction technique.

CHAPTER #3: BACKGROUND

Crabtree and Bourdes, among others (Johnson, 1978), revived flintknapping as a technology by replicating knapped chert or obsidian tools to learn what had happened at each stage of a tool's manufacture. To do this, they studied the flintknapping of Ishi and modern gunflint makers (Coles, 1979) before replicating lithic tools of their own (Crabtree, 1966). By experimenting with different techniques, they successfully reverse-engineered ancient artifacts to learn how flintknappers made them (Crabtree, 1966).

Crabtree, in particular, proved the utility of stone blades in surgery (Buck, 1982) by experimenting on himself with the assistance of a trained surgeon. When Crabtree was due to undergo heart surgery in 1975, he custom-knapped several surgical blades from obsidian and then requested the surgeon at least use the obsidian blade to create half of the initial incision in his chest. According to the surgeon, the incision created with the obsidian blade was cleaner and less ragged, the obsidian blade held its edge longer than the metal scalpel blade, and the wound created by the obsidian blade healed much more rapidly and with less risk of infection than that created by the metal scalpel (Buck, 1982). Not only did this experiment prove that certain medical techniques were not as out of the reach of prehistoric peoples as was previously thought, it led to further experiments and eventually the use of obsidian blades in certain surgeries (Buck, 1982).

Experimental archaeology can take on forms other than artifact replication. Other experiments in archaeology include various types of cooking and storage to replicate residues and heating patterns. In the case of the *Kon-Tiki*, the somewhat flawed experiment entailed building a raft and sailing across the Pacific Ocean to test whether human populations could have spread this way in the past (Heyerdahl, 1968). These experiments all serve as guides to what behaviors may have occurred to create archaeological finds, and while on their own they cannot conclusively prove the sequence of events leading up to the discovery of a site, they can provide insights into the actions and minds of the people who created the artifacts and sites that would later be found.

The atlatl has been subjected to archaeological experimentation for some time. Its history of experimentation goes back to Browne's attempts to compare the effectiveness of the atlatl and dart to the bow and arrow (Browne, 1940). In the 1980s, Frison used his own atlatl and dart system to hunt elephants during a planned cull (Frison, 1989), and Perkins and Leinenger first compared the accuracy of flexible and rigid darts (Cahill, 1987). Whittaker, Perkins, and Hrdlicka, experimental archaeologists who focus on the atlatl and dart, have performed many experiments of their own about various factors that may affect the atlatl's performance.

The atlatl and sling share their basic physics with many other force multiplier weapons. The trebuchet, for example, is a large siege engine used against fortified defenses that uses a very large mechanized sling to hurl ammunition (Gurstelle, 2004). A possible variant of the atlatl exists in the *baton de commandement*, which used a tension cord wound around the user's thumb to assist in the throwing motion (Comstock, 1999). The sling staff, though classed as a type of sling weapon (Gurstelle, 2004; Harrison, 2006; Hawkins, 1846; Korfmann, 1973; Savage, 1999), combines some of the arm extension and arcing throwing motion of the atlatl with the flexible pouch and flexibility of ammunition of the sling. However, the common “ancestors” or “descendents” of these weapons are under discussion.

The Atlatl

The atlatl is one of the oldest force multiplier weapons known to humans (Fogelman, 1997; Kellar, 1955; Thieme, 1997). Although the atlatl derives its name from two Aztec words that, according to Nuttall, indicate its use in fishing (Nuttall, 1891; Webb & DeJarnette, 1942), the atlatl may predate modern humans. The Schöningen site in Germany, which dates to approximately 400,000 BP, contains the remains of several light darts that appear to be made to be thrown rather than thrust (Thieme, 1997). Also found in this same layer was a shorter wooden implement that may have been a primitive form of the atlatl, although this cannot yet be confirmed. This may mean that the atlatl’s use extends as far back as the species *H. heidelbergensis*, a predecessor to the Neanderthal, and predating modern humans. However, the earliest dates for confirmed atlatls found in the archaeological record is approximately 19,000 BCE to 12,000 BCE (Fogelman, 1997; Raymond, 1986), indicating its earliest use by physically modern humans of the Paleolithic period in the Dordogne region of France (Webb, 1957).

The atlatl has appeared in multiple locations around the world, including, among others, the Australian woomera and Inuit throwing boards (Fogelman, 1997; Kellar, 1955; Vanderhoek, 1998; Webb, 1957), but they all share several characteristics regardless of geography. At the distal end, the atlatl has a means by which to connect to the dart it throws, although these connections vary between a hook (“male”) as was seen in many European archaeological atlatls, a groove (“female”), or a combination of both (“mixed”) as seen in many Great Basin archaeological finds (Fogelman, 1997; Mildner, 1974; Vanderhoek, 1998). The user grips the proximal end of the atlatl as a dart is put in place, putting their hand under the shaft and lightly steadying the dart with a finger and thumb or two fingers. Finger loops, drilled holes, or shaped grips may accommodate the user but are not essential (Fogelman, 1997; Kellar, 1955; Knapp, 2010; Laird, 1984; Pewtherer, 2010; Tuomala, 2000; Vanderhoek, 1998).

The dart that the atlatl is made to throw also varies according to the user's needs. The dart is often made of flexible wood (Baugh, 2002; Fogelman, 1997). The dart can be a "self" dart, constructed from one piece of wood with or without a stone point, or can be a compound dart, which has a detachable point that notches into the shaft (Fogelman, 1997; Frison, 2004; Vanderhoek, 1998; Webb, 1957).

The atlatl works by increasing the effective length of the user's arm and using the wrist like a second elbow to create extra force above and beyond the normal throwing motion of the human arm. This increases the acceleration of the dart, ideally compressing and often flexing the dart's shaft (Raymond, 1986; Whittaker, 2005) before it launches, sometimes at speeds of 80-100 miles per hour (Fogelman, 1997). The stance and motion of the user's body during the throw can also alter the force behind the dart's throw (Fogelman, 1997; Knapp, 2010; Whittaker, 2005).

Atlatls in North America, particularly those found east of the Mississippi River, often possess bannerstones (Kellar, 1955). Bannerstones are specially shaped stones attached to the midshaft of an atlatl (Kinsella, pers. comm., June 24, 2012; Perkins, 1992). The cultural and functional purpose of bannerstones is currently under scholarly debate (Fogelman, 1997). Several archaeologists believe them to be markers of status or lineage, due to their variety of shape and size, some of which are so large as to be hazardous to the user (Strischek, 1995). While some have theorized them to fulfill other functions, such as weights for spinning thread (Bruechert, 1996), Perkins has suggested that bannerstones acted as hunting silencers by muffling or otherwise disrupting the noise caused by the atlatl's motion in a way that quiets the throw (Perkins, 1992). Kinsella instead thinks that bannerstones were meant to balance against a front-heavy dart. Both have tested their respective theories, the preliminary results of which support their hypotheses (Kinsella, pers. comm.. June 24, 2012; Perkins, 1992).

The lengths of the atlatl and dart can vary widely due to different functional requirements. Perkins has noted that atlatls found east of the Mississippi River in North America tend to be shorter than those found west of the river and believes this to be a result of a difference in vegetation that allowed hunters to approach their prey more closely in the eastern United States (Perkins, 1992). However, while the "general" range is between one and two feet (0.3-0.6 m) (Fogelman, 1997), the variation can be quite wide even in a relatively small geographical area (Mildner, 1974). The shortest atlatl discovered to date is approximately 14-15 cm in length (Kellar, 1955). One modern writer and enthusiast has constructed multiple personal atlatls ranging between 8 and 48 inches (0.2-1.2 m) in length, although the two extremes of the size range are impractical for serious hunting or defense (Wescott 1999a). The darts range from 4 to 9 feet (1.2-2.7 m) in length, also depending on range and the size of the atlatl they correspond to.

The atlatl saw use in military settings in antiquity in addition to its use in hunting. The Aztec empire used it to great effect in conflicts (Nuttall, 1891). Contrary to legends, Whittaker believes that the atlatl was ineffective in piercing the conquistadors' plate armor after testing this theory in modern experiments. However, the darts would have pierced light mail, padded cotton, or leather armor (Whittaker, 2009). However, the atlatl is primarily considered a hunting weapon.

The atlatl's use has continued in limited fashion into the modern age. Some survival manuals give instructions on making and throwing a very rough atlatl and dart as a means of self-defense and hunting (Pewtherer, 2010). Other enthusiasts put out instructions for hobbyists to make and use their own (Hrdlicka, 2002a; Knapp, 2010). For hands-on learners and enthusiasts, there are several clubs, the World Atlatl Association chief among them, where the skill may be learned. Several of these organizations hold regular competitions where entrants may offer new designs (Laird, 1984; Tuomala, 2000), compete in several categories (Fogelman, 1997), and otherwise treat the atlatl as any other weapon in a sporting event.

Modern records have even been set. As of July 15, 1996, the distance record with any type of equipment has been 848.56 feet (258.47 meters) (Fogelman, 1997), while the distance using strictly "primitive" equipment stands at 585.5 feet (178.34 meters) (Fogelman, 1997). While these are records and thus beyond what most atlatl users could achieve, they do indicate the weapon's potential.

Many states have even legalized the use of the atlatl and dart as a hunting weapon. Missouri has permitted hunters to pursue deer with atlatls during the firearms hunting season since 2010 (Mertz, 2011). In Texas, the atlatl and dart have been permitted in the hunting of feral swine, indicating a vote of confidence for this particular weapons system. At least two atlatl users have successfully hunted this particular prey. Berg's account of using an atlatl to bring down a hog indicates the atlatl's effectiveness in hunting dangerous game (Berg, 2004; Fogelman, 1997).

Although the atlatl competes with firearms and modern archery in this hunting context, it is comparable to its competitors in effectiveness. A light atlatl dart thrown at 50 mph would strike with slightly more force than an arrow shot from a modern bow and has more piercing power than most modern firearms (Hrdlicka, 2003). Its capability in this regard makes its neglect in modern hunting a matter of oversight rather than ineffectiveness.

The atlatl has been used in several modern hunting experiments to test its effectiveness. One in particular proved its stopping power against a wounded elephant (Frison, 1989). This demonstration of the atlatl's power on megafauna does show how it could have been used against even larger and quite possibly more dangerous prey. Frison's work in this experiment, as well as others, also brought to light how several people working in a team might have cooperated to bring down prey (Frison, 1989; Frison, 2004). The atlatl's long history, both in hunting and warfare, shows that it is an impressive piece of technology that is now regaining the recognition it deserves.

The Sling

The atlatl is not the only force multiplier weapon that has seen military and hunting use for thousands of years. The sling has as much of a military history as a civilian hunting history (Dohrenwend, 2002; Harrison, 2006; Korfmann, 1973; Richardson, 1998; Savage, 1999; York & York, 2011). Though its history appears not to extend as far back as that of the atlatl, archaeological evidence is spread across the world (Dohrenwend, 2002; Heizer & Johnson, 1952; Korfmann, 1973; York & York, 2011). Its modern use, while limited compared to its past applications, continues into the present as a sporting and survival weapon.

Currently, the sling is believed to be a more recent invention than the atlatl, with evidence of its existence extending back only as far as 8,000 BCE (Dohrenwend, 2002). This may be because the sling was made of perishable leather, plant fibers, or hair of varying kinds (Cahlander, 1980; Dohrenwend, 2002; Korfmann, 1973, Richardson, 1998; Savage, 1999; York & York, 2011). Sling bullets of rock, clay, or metal (Dohrenwend, 2002; Greep, 1987; Harrison, 2006; Richardson, 1998; Savage, 1999; York, 2011) have been found as early as 8,000 BCE (Dohrenwend, 2002). Slings themselves, which do not require specially made bullets to operate (Dohrenwend, 2002; Gurstelle, 2004; Harrison, 2006; Korfmann, 1973; Savage, 1999), have been found only as early as 4,000-6,000 BCE (Dohrenwend, 2002). However, being a more recent invention does not make the sling any less powerful than the atlatl.

Slings all share a basic design. A sling will consist of two long cords on either side of a small central pocket (Cahlander, 1980; Dohrenwend, 2002; Gurstelle, 2004; Heizer & Johnson, 1952; Korfmann, 1973; Richardson, 1998; Savage, 1999). Several variations include a loop for a finger or wrist at the end of one cord to secure it to the user's hand (Gurstelle, 2004; Korfmann, 1973; Savage, 1999), a knot at the end of the release cord (Gurstelle, 2004; Korfmann 1973; Savage, 1999), and/or a slit that splits the pocket lengthwise along its center (Cahlander, 1980; Savage, 1999; Slinging.org, 2011). The overall length of a sling varies to allow different ranges and techniques (Richardson, 1998; Savage, 1999), but a medium-range or all-purpose sling's length will be approximately 50-60 inches (1.3-1.5 m) long (Savage, 1999), or roughly the span of an adult user's arms. While there are no hard and fast rules for functional slings, these variants frequently appear in ancient and modern designs (Cahlander, 1980; Gettleman, 2008; Gurstelle, 2004; Heizer & Johnson, 1952; Korfmann, 1973; Potter 2009; Savage, 1999; Slinging.org, 2011).

Similar to the atlatl, the sling works by effectively extending the arm of the slinger to allow the slinger to throw with a greater velocity than would be possible otherwise. The slinger holds both ends of the sling in one hand with the projectile seated in the pouch and swings the sling to build up speed (Dohrenwend, 2002; Gurstelle, 2004; Richardson, 1998; Savage, 1999). The release cord is released with a snap of the wrist so that the projectile flies towards the target (Dohrenwend, 2002; Gurstelle, 2004; Korfmann, 1973; Richardson, 1998; Savage, 1999). Contrary to popular myth, multiple rotations prior to throwing do not improve aim or range and may in fact harm both (Forsyth, 2011).

The sling was a popular weapon of war for individual soldiers and large armies. Considering its ability to hurl stones or metal “bullets” with force and velocity akin to personal firearms (Dohrenwend, 2002; Greep, 1987; Korfmann, 1973; Richardson, 1998); and its versatility in ammunition (Dohrenwend, 2002; Savage, 1999; Slinging.org, 2011), the sling’s application in warfare is unsurprising.

Two of the most famous groups to use the sling in a military context were the slingers of the Balearic Islands, who, while not Greek, were used by the Greek military and the Achean slingers of ancient Greece (Dohrenwend, 2002; Gurstelle, 2004; Harrison, 2006; Savage, 1999). The ancient Greek slingers were trained from childhood and were the slingers of choice for their accuracy and their ranges, while both groups were credited with abilities such as being able to hit a specific point on a man’s face from more than half a kilometer away or send a rock through a hoop at an unspecified great distance (Harrison, 2006). The Balearic slingers in particular were so renowned for their skills with the sling that they were sought after as mercenaries from Ancient Greek times through the late Medieval period (Dohrenwend, 2002; Harrison, 2006).

Much of the body of knowledge about the sling's military use comes from the Mediterranean region during the Ancient Greek and Roman eras. The sling was essential to Persian, Greek, and Roman military forces during times of massed conflict (Dohrenwend, 2002; Gurstelle, 2004; Richardson, 1998). Although slingers were accorded less status than heavy infantry, when massed, they were often vital to an army's success (Dohrenwend, 2002; Hawkins, 1846; Korfmann, 1973). Sling bullets are still a common find in Roman military sites (Greep, 1987; Korfmann, 1973; Richardson, 1998; Savage, 1999).

The sling's low status did not necessarily relate to its effectiveness. As mentioned before, slingers were vital to an army (Dohrenwend, 2002; Hawkins, 1846; Korfmann, 1973). There were even instructions included in a Roman doctor's text for removing embedded sling bullets from a human body (Harrison, 2006), which may indicate how frequently this occurred. The sling even merits several passing mentions as part of the battle scenes in the *Iliad*, although it is only named as such when one is being used as an improvised wound dressing (Ballard, 1985; Korfmann, 1973), but it is used at least once to kill a character in the *Aeneid* (Richardson, 1998). Its appearance in art is equally diminished compared to its importance in the military, with only a few reliefs and frescoes depicting slingers (Hawkins, 1846). In spite of the low status afforded most slingers in ancient military settings (Dohrenwend, 2002; Korfmann, 1973), they were vital to the army and fearsome alone or in massed combat.

The use of slings in combat settings, although most often recorded in the Mediterranean region, was common around the world. The sling was used equally as a hunting weapon and war weapon in Oceania (York & York, 2011) until relatively recently. Hilltop fortifications in the Andes can be typed as the sites of conflicts or of defensive sites by the presence of slingstones (Arkush, 2008). The sling's presence in fibercraft continues to this day (Cahlander, 1980; Collingwood, 1987). During the Spanish conquest of Central and South America, slings were often the weapons first encountered by the conquistadors (Dohrenwend, 2002; Korfmann, 1973), who recorded the surprising effectiveness of the sling as being comparable to a shot from a musket.

The sling remained a viable military weapon until fairly recently in human history. In Medieval Europe, most armies recruited slingers, including Balearic slingers (Harrison, 2006), until mass-produced accurate firearms, alterations in fortifications that shielded attacking ranged weapons, and changes in infantry armor rendered slings ineffective and thus obsolete. In some cases, this transition in weaponry took place as late as the 16th or 17th century (Harrison, 2006; Korfmann, 1973), indicating the sling's power on the battlefield in the hands of a skilled user even as its popularity waned.

The sling saw as much use in peacetime hunting as it may have had on the battlefield. Hunting slings have been found in Egyptian sites, the design and construction of which have been approximated by a modern hobbyist (Potter, 2009). As previously mentioned, its use in hunting was equal to its use in conflict in Oceania, and it was considered a "man's weapon" (York & York, 2011). It has also seen heavy use by shepherds. However, activities such as chasing away nuisance animals or herding animals do not necessarily require a high degree of accuracy.

In spite of being phased out as a military weapon, the sling has survived into modern times in a limited fashion. Adolescents and adults use it as a sporting weapon (Gurstelle, 2004; Korfmann, 1973) and combat weapon (Gettleman, 2008; Savage, 1999). The sling is currently subject to few hunting restrictions in the United States (Slinging.org, 2011), unlike the atlatl.

The sling has seen less experimentation than the atlatl in archaeology, although some data has been collected. The record for distance with an ordinary stone rather than specialized shot is 437.1 meters (1434 ft) (Slinging.org, 2011), while the distance record with a biconical lead bullet is 505 meters (1656.8 ft) (Slinging.org, 2011). The records are extraordinary, but ordinary slingers can throw 80-150 meters (262.5-492 ft) when using specialized shot (Harrison, 2011; Richardson, 1998). If these experiments indicate the sling's power, the ranges of the Balearic slingers may not be as much of an exaggeration as previously thought. Some enthusiasts have experimented with the range lent by different shapes and weights of sling bullets (Harrison, 2011; Richardson, 1998) and different types of throws (Harrison, 2011) and calculated the physics at work (Alsatian, 2011; Dohrenwend, 2002), but the sling has not been subjected to the same extent of experimentation as the atlatl.

The history of both the sling and atlatl in military and civilian use, in both prehistoric and historic times, indicates their effectiveness. Their long military use, civilian uses, and their modern revival reflects their power in competent hands. But there is little to indicate which would be the more quickly learned and which the more accurate. The comparison in learning times, ranges, and benefits for novice users may shed light on why both weapons appeared so early in human history and persisted for as long as they did.

CHAPTER #4: MATERIALS AND METHODS

This experiment is only a pilot study and does not have sufficient data for in-depth analysis. However, the data collected is sufficient for exploratory statistics and to support or disprove these three hypotheses.

Hypotheses

The hypotheses for this experiment were as follows:

1) The atlatl would be mastered more quickly than the sling, as measured by composite scores and practice time.

2) The atlatl would be a more accurate weapon than the sling.

3) The sling would have a longer effective range than the atlatl.

Before testing could begin, the weapons had to be manufactured and used by the author to test their relative strengths and weaknesses, to avert any potential problems or hazards, and to formulate hypotheses about the experiment to come. In practice, this meant that several variations on weapon and ammunition design were tested before the final variant for each was chosen for the experiment.

Weapons

The atlatls manufactured for the volunteers were designed with speed of manufacture and utility in mind. These atlatls were constructed from 1-inch diameter wooden dowels, with a hole drilled at a 45-degree angle at the far end into which a blunt-pointed ¼-inch wooden peg was glued. While this design followed Hrdlicka (2002a), each atlatl was sized by length to match the length of the volunteer's forearm from elbow to fingertip. If a volunteer had a 45-cm forearm from elbow to fingertips, they would receive a 45-cm atlatl. This gave each volunteer a mechanical advantage proportional to their stature. Uniform atlatls would have forced the volunteers to use weapons that would have been improperly sized for their proportions. Finger loops, wrist loops, and weights such as bannerstones were not included in this design. As a 1-inch diameter wooden dowel does not appreciably flex, flexibility was not taken into consideration.

One disadvantage to these expedient atlatls was the weakness of the peg forming the hook, which completely snapped off for four of the five volunteers before the end of testing. When this occurred, the atlatl was given a new hook made of a long metal screw, returned to the volunteer, and testing with the atlatl resumed.

The preliminary sling design involved a split pouch. However, this proved unfeasible for the experiment because ammunition tended to escape the sling in such unpredictable ways as to be dangerous to the slingers and observers. A solid woven pouch (Slinging.org, 2011) was more predictable. Slings for volunteers were braided out of 5/32-inch synthetic rope, with solid woven pouches, trigger knots, and finger loops, each fitted so that a volunteer with a 90-cm arm length from outstretched fingertips to sternum received a 180-cm sling. All knots and loose strands were secured with glue to prevent unraveling.

Ammunition

Ammunition for each weapon needed to be consistent in size and mass and somewhat aerodynamic, easily obtained, and modifiable for use. Just as with the weapons themselves, the darts and "stones" went through several designs and tests of their own before a preferable design was found. Findings from archaeological sites, results of experimental archaeology, and the recommendations of modern hobbyists were all invaluable in this regard.

The darts for the atlatl were inspired by Hrdlicka's dart design (Hrdlicka, 2002b). Darts initially tested for the atlatl were both 3/8-inch and ½-inch diameter dowels purchased from a hardware store, all 4 feet in length, equipped with blunt metal target point arrowheads. The first generation had the points glued into drilled sockets in the distal end and a socket for the atlatl drilled in the proximal end. The second generation had the point end whittled for a more aerodynamic profile and then firmly bound with mason twine to prevent the carved wood from splitting. Like the first design, a socket and point were included. Without fletching, the darts were prone to tumbling in flight. All of the wooden darts tended to warp and bend out of true regardless of storage method. Even with fletching, these wooden darts' flight paths would curve so low as to "skip" off the ground rather than fly straight as desired (Baugh, 2002; Cahill, 1987).

The final dart design was a modified, 4-foot-long, ¼-inch diameter fiberglass pole. The fiberglass was lightweight, flexible, and sturdy. The design of the poles meant that the darts were already uniform in length, diameter, and mass; could be purchased in nearly complete form; and required only the addition of fletching and a butt socket. The fletching was two vanes constructed of duct tape and milk jug plastic. These vanes were longer and wider than ordinary arrow fletching to keep the proportionately larger dart stable, as specified by Hrdlicka (2002b). The materials for the vanes were specifically chosen for being readily available, lightweight, durable, and easy to repair or replace in the field. Two finished darts were issued to each volunteer with which to practice, and ten were held in reserve for testing sessions.

Slings require much less specialized ammunition to function as weapons, but for the purposes of consistency and safety, something other than smooth stones or molded clay shot had to be selected. Leather juggling balls and hackysacks were considered for their safety but rejected for softness, inconsistency in size and mass, and a lack of weight needed for the sling to operate properly. Stones were never considered due to their inconsistent size and the danger they presented. Novices are likely to send a sling's shot in any direction, including vertically (Savage, 1999). Sand balls offered a measure of safety but, because they self-destruct on impact, would have made distinguishing individual hits on the target difficult. Golf balls were eventually selected as ammunition, due to their size, uniformity, ready availability, and proven aerodynamic design. For testing, each volunteer was issued ten golf balls, each spray-painted with a different color on one side. Lost balls were replaced when necessary.

A target for the testing phase was constructed from a large cardboard box stuffed with Styrofoam and newspaper to slow or stop any projectiles without sacrificing portability. The box was then covered with butcher paper, upon which a target 60 cm in diameter with 10 rings forming a bullseye was drawn in black permanent marker. The rings were scored from 1 to 10 from the outmost to inmost ring, with numbers indicating their score marked on the top and bottom of each ring for ease of reading and recording. A target was replaced when necessary. The purpose of this bullseye target on the box was to measure accuracy and reward the most accurate throws appropriately.

The box with the target was taken to an open field and secured against a tree away from cars and houses. A throwing range was then set up, with flags marking distances of 5, 10, 15, 20, and 25 meters as measured from the central bullseye of the target.

Each volunteer was advised on proper technique to avoid endangering themselves or others. For safety and consistency, the volunteers were all instructed to use an overhanded vertical slinging throw rather than an underhanded or overhead horizontal “helicopter” throw.

For each testing session, the volunteer in question had to stand at each of the five distance markers and:

- throw the golf balls barehanded 10 times
- throw the golf balls with the sling 10 times
- throw the atlatl darts barehanded 10 times
- throw the atlatl darts with the atlatl 10 times.

The scores for each set were recorded as appears in the Master Data Table (Appendix). A thrown missile that struck the target was awarded a number of points equal to the ring it struck. A missile that struck the box outside of the target’s outermost ring were awarded half a point each, and throws that missed the box altogether, bounced off of any obstacle before striking the box, or “skipped” off the sides of the box were not awarded any points. Those that struck a line on the bullseye were awarded the points of the ring that 51% or more of the dart or golf ball had landed in. All of this was done to learn how accurate a volunteer was without the assistance of the force multiplier, how accurate they were with each weapon, and how accuracy varied by distance. The series of tests was done to learn if accuracy increased with practice.

In addition to the above procedures, another test was used to measure maximum distance. Such designated distance throws were made, both barehanded and aided by the weapons, once per testing session along a straight line. This was intended to show what the absolute maximum range for the weapons and their unassisted ammunition could be if accuracy was not a factor. The distance where the missile in question first struck the ground was recorded to the nearest half-meter along a straight line. The designated distance throw was also awarded points, one point per meter, which was then factored into the composite score for that weapon in that testing session. As each volunteer’s schedule allowed, this series of tests was repeated three times.

However, the distance achieved during the designated distance throw was not necessarily the maximum distance achieved during a test. If a target throw missed and exceeded the distance of a designated distance throw, this was recorded for later reference. This occurred frequently enough to warrant consideration, though it earned no points.

Practice times between testing sessions were also recorded for each volunteer, with the hope of noting what amount of practice showed the greatest improvement so as to grasp the amount of time it would take for novice volunteers to master the weapons. Volunteers were instructed not to practice prior to their first session of tests to gauge how novices would handle the weapons with no prior familiarity. After that “baseline” reading of their performance, volunteers were allowed to practice with their weapons as much as they wished on their own time, and their self-reported times were recorded. After the end of all three testing sessions, the volunteers were allowed to keep their personal atlatl, sling, and golf balls as a gesture of thanks for their participation.

The risk of volunteers practicing exclusively with one weapon to the detriment of the other was taken into consideration during the formulation of the tests. The use of all categories to determine the winner of any particular testing session was meant to combat this particular issue, as was instructing the volunteers that they were expected to practice with the weapons in preference to throwing the ammunition barehanded. Volunteers had previously been cautioned against approaching or interfering with a throwing volunteer during practice due to the danger involved.

It had been previously decided that the volunteer with the best total scores for each testing session would be rewarded with a loaf of homemade banana bread. To compensate for any natural advantage or disadvantage according to stature, the volunteer whose score was proportionately highest compared to his or her arm length would be deemed the winner. See Results and Analysis for details. These same adjusted scores would also allow analysis of how a group of volunteers with the same arm and forearm measurements would have improved over time. These indexed scores are reported as “Adjusted” in all tables and the Appendix. The various scores were analyzed to control the effect of arm length and stature on overall performance.

CHAPTER #5: RESULTS AND ANALYSIS

Because this experiment is only a pilot study and proof of concept, it does not offer enough data for in-depth statistical analysis. Exploratory statistics, which will be used for this analysis, are more appropriate for this small dataset.

The three hypotheses tested in this experiment are:

1) The atlatl would be mastered more quickly than the sling, as measured by composite scores and practice time.

2) The atlatl would be a more accurate weapon than the sling.

3) The sling would have a longer effective range than the atlatl.

The first hypothesis, that the atlatl would be more quickly learned as measured by composite scores, could not be supported or disproven due to insufficient data for practice time by the volunteers. The second hypothesis was supported. The atlatl was more accurate than the sling. The third hypothesis that the sling would have the greater range was supported, although this support is quite weak both when using the fifteen distance throws and the means of all distance throws. While the barehanded throws tended to be longer than the throws assisted by the force multipliers, indicating the volunteers' lack of mastery of either multiplier, the final results of all of the sessions showed that there was more affecting each volunteer's learning curve than the composite scores indicated.

Each volunteer's table is broken down by the weapon being used. The volunteer's score at each distance marker is recorded in the appropriate column, out of a possible 100 points at each marker. The accuracy total is the sum of points for all five distances. The distance throw column records the distance in meters that the dart or ball covered before striking the ground. The composite score is the sum of the accuracy total plus the distance throw.

Adjusted scores are calculated as though every volunteer had a forearm length of 44.3 cm and an arm length of 88.6 cm. For the atlatl and dart, the formula for adjusted accuracy is:

Accuracy Total X (Standard forearm/Volunteer forearm) = Adjusted Accuracy

For the ball and sling, the formula for adjusted accuracy is:

Accuracy Total X (Standard arm/Volunteer arm) = Adjusted Accuracy

The adjusted composite score for the dart and atlatl is calculated as follows:

Composite Score X (Standard forearm/Volunteer forearm) = Adjusted Composite

The adjusted composite score for the ball and sling is calculated as follows:

Composite Score X (Standard arm/Volunteer arm) = Adjusted Composite

These transformations of accuracy and composite scores were done to control for the effects of differences in volunteer stature by standardizing values.

Volunteer #1

Volunteer #1 (Table 1), the longest limbed volunteer of the group and the most diligent about practice, reported no more athletic experience than unorganized recreation.

Table 1. Volunteer #1: Forearm 52.9 cm, Arm 100.9 cm

Session	Practice	Accuracy Throws						Distance	Composite	Adjusted	Adjusted
	(Hours)	5m	10m	15m	20m	25m	Total	Throw	Score	Accuracy	Composite
		(pts)	(pts)	(pts)	(pts)	(pts)	(pts)	(pts = m)	(pts)	(pts)	(pts)
Dart (1)	0.0	10.5	0.5	0.0	0.0	0.0	11.0	25.0	36.0	9.2	30.2
Dart (2)	0.0	3.0	0.0	0.0	0.0	0.0	3.0	30.0	33.0	2.5	27.7
Dart (3)	0.0	10.5	1.5	0.5	0.0	0.0	12.5	26.0	38.5	10.5	32.3
Total	0.0	24.0	2.0	0.5	0.0	0.0	26.5	81.0	107.5	22.3	90.2
Mean	0.0	8.0	0.6	0.2	0.0	0.0	8.8	27.0	35.8	7.4	30.1
Atlatl (1)	0.0	7.0	0.0	0.0	0.0	0.0*	7.0	26.0	33.0	5.9	27.6
Atlatl (2)	8.0	0.5	8.0	0.0	0.0	0.5	9.0	30.0	39.0	7.6	32.8
Atlatl (3)	8.0	6.5	0.5	0.0	0.0	0.0	7.0	10.0	17.0	5.9	15.1
Total	16.0	14.0	8.5	0.0	0.0	0.5	23.0	66.0	89.0	19.3	75.5
Mean	5.3	4.7	2.8	0.0	0.0	0.2	7.6	22.0	29.6	6.4	25.2
Ball (1)	0.0	17.0	1.5	1.0	0.5	1.0	21.0	47.5	68.5	18.5	60.3
Ball (2)	0.0	4.5	2.0	0.5	0.0	0.0	7.0	25.0	32.0	6.2	28.2
Ball (3)	0.0	48.0	8.0	4.5	8.0	0.0	68.5	37.5	106.0	60.3	93.3
Total	0.0	69.5	11.5	6.0	8.5	1.0	96.5	110.0	206.5	84.9	181.8
Mean	0.0	23.2	3.8	2.0	2.8	0.3	32.2	36.6	68.8	28.3	60.6
Sling (1)	0.0	6.0	0.5	0.0	0.0	0.0	6.5	35.0	41.5	5.7	36.5
Sling (2)	3.5	5.0	0.5	0.5	0.0	0.0	6.0	35.0	41.0	5.3	36.1
Sling (3)	8.0	3.0	1.0	0.0	0.0	0.0	4.0	20.0	24.0	3.5	21.1
Total	11.5	14.0	2.0	0.5	0.0	0.0	16.5	90.0	106.0	14.5	93.7
Mean	3.8	4.7	0.7	0.2	0.0	0.0	5.5	30.0	35.3	4.8	31.2

Note: All values have been rounded to one decimal.

Dart/Atlatl

Volunteer #1’s accuracy with the hand-thrown dart improved slightly over the three sessions, as did his distance. Although the trend was one of overall improvement, his distance score improved only slightly between the first and third sessions.

When armed with the atlatl, Volunteer #1’s accuracy remained nearly the same over the three sessions. His distance initially improved, then decreased greatly in the third session. However, he was able to strike the target from the 25-meter distance marker, something he could not do when throwing the dart barehanded.

Ball/Sling

With the hand-thrown ball, Volunteer #1's accuracy, distance, and composite scores all started high, decreased in the second session, and then improved greatly in the third session. His accuracy and composite scores were higher in the third session than in the first. However, his distance score remained below what it had been in the first session.

Volunteer #1's accuracy with the sling decreased with time and never reached the level of his barehanded ball throw. His accuracy with the sling exceeded that of his hand thrown dart only in the second session, but overall the sling had the lowest accuracy of all his weapons. His distance score with the sling, however, was higher than that of the atlatl until the third session, and his mean distance score was greater than that of the atlatl. With all but the dart, his distance score decreased over time.

Volunteer #1's data support both the hypothesis that the atlatl is the more accurate weapon and the hypothesis that the sling would have a greater range. Although his data disproves the hypothesis that the atlatl would be more quickly learned as measured by time and composite scores, his data alone cannot be considered the rule for this experiment.

Volunteer #2

Volunteer #2 (Table 2), with the shortest arm and forearm measurements, claimed several years of experience pitching in women's softball.

Table 2. Volunteer #2: Forearm 40.6 cm, Arm 77.5 cm

Session	Practice (Hours)	Accuracy Throws 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Total (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)
Dart (1)	0.0	14.5	2.0	0.0	0.0	0.0	16.5	19.0	35.5	18.0	38.7
Dart (2)	0.0	9.0	2.0	0.5	0.0	0.0	11.5	19.0	30.5	12.5	33.2
Dart (3)	0.0	17.0	4.0	0.0	0.0	0.0	21.0	20.0	41.0	22.9	44.7
Total	0.0	40.5	8.0	0.5	0.0	0.0	49.0	58.0	107.0	53.4	116.6
Mean	0.0	13.5	2.6	0.2	0.0	0.0	16.3	19.3	35.6	17.8	38.9
Atlatl (1)	0.0	9.5	8.5	0.0	0.0	0.0	18.0	10.0	28.0	19.6	30.5
Atlatl (2)	0.0	0.5	0.0	0.0	0.0	0.0	0.5	15.0	15.5	0.5	16.9
Atlatl (3)	0.0	4.0	1.0	4.5	0.0	0.0	9.5	22.5	32.0	10.4	34.9
Total	0.0	14.0	9.5	4.5	0.0	0.0	28.0	47.5	75.5	30.5	82.3
Mean	0.0	4.6	3.2	1.5	0.0	0.0	9.3	15.8	25.2	10.1	27.4
Ball (1)	0.0	25.0	12.5	2.0	1.0	0.0	40.5	40.0	80.5	46.2	91.8
Ball (2)	0.0	42.0	6.0	0.5	0.5	9.5	58.5	27.0	85.5	66.7	97.5
Ball (3)	0.0	49.5	4.0	6.0	5.5	0.5	65.5	25.0	85.5	74.7	97.5
Total	0.0	116.5	22.5	8.5	7.0	10.0	164.5	102.0	251.5	187.5	286.8
Mean	0.0	38.8	7.5	2.8	2.3	3.3	54.8	34.0	83.8	62.5	95.6
Sling (1)	0.0	0.0	0.5	6.0	0.0	0.0	6.5	20.0	26.5	7.4	30.2
Sling (2)	0.0	3.5	0.5	0.5	5.0	0.0	9.5	21.0	30.5	10.8	34.8
Sling (3)	0.0	6.5	0.0	0.0	0.0	0.0	6.5	15.0	21.5	7.4	24.5
Total	0.0	10.0	1.0	6.5	5.0	0.0	22.5	56.0	78.5	25.7	89.5
Mean	0.0	3.3	0.3	2.2	1.6	0.0	7.5	18.6	26.2	8.6	29.8

Note: All values have been rounded to first decimal.

Dart/Atlatl

When throwing the dart barehanded, Volunteer #2's accuracy was high at the 5-meter distance marker but decreased significantly at farther distance markers. Her distance score was consistent across all three sessions.

The atlatl's accuracy started higher than that of the dart in the first session, but then decreased to below that of the dart through the second and third sessions. It must be noted that, while its accuracy was lower than the hand-thrown dart, its accuracy score was spread more evenly over the same distance markers. Its distance score started below that of the dart but increased until it was greater than that of the dart in the third session. However, its mean distance was still less than that of the dart. Her composite score also remained below that of the dart for all three sessions.

Ball/Sling

Volunteer #2's barehanded ball throws showed her experience as a softball pitcher. Her accuracy started high and increased over the three sessions. In addition, she was able to score on the target from the farthest distance marker. However, her distance started high and decreased steadily over all three sessions.

Volunteer #2's accuracy with the sling increased in the second session, then decreased in the third session, although it never decreased to below what it had been in the first session. Her distance with the sling increased between the first and second trials. However, the third testing session saw a decrease in her composite score and distance score to below her scores at the first testing session and a decrease of her accuracy to the same point as the first testing session. Her mean scores in all categories were also consistently much lower than those of the barehanded ball throws.

Although her barehanded ball throws had the best scores, Volunteer #2 was more accurate with the atlatl than with the sling, supporting the second hypothesis. The mean sling distance was greater than the mean atlatl distance, so the third hypothesis is tentatively supported. No relationship between practice and scores could be established, as this volunteer did not practice between sessions, meaning the first hypothesis cannot be supported or disproven.

Volunteer #3

Volunteer #3 (Table 3), with the second shortest arm and forearm measurements of the group, claimed no prior experience or athletic practice but acknowledged that she had a dog toy that was used in much the same way as an atlatl.

Table 3. Volunteer #3: Forearm 41.8 cm, Arm 82.4 cm

Session	Practice (Hours)	Accuracy Throws 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Total (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)
Dart (1)	0.0	12.0	0.0	0.0	0.0	0.0	12.0	10.0	22.0	12.7	23.3
Dart (2)	0.0	2.5	0.0	0.0	0.0	0.0	2.5	10.0	12.5	2.7	13.3
Dart (3)	0.0	2.0	0.0	0.0	0.0	0.0	2.0	13.0	15.0	2.1	15.9
Total	0.0	16.5	0.0	0.0	0.0	0.0	16.5	33.0	49.5	17.5	52.5
Mean	0.0	5.5	0.0	0.0	0.0	0.0	5.5	11.0	16.5	5.8	17.5
Atlatl (1)	0.0	0.5	0.0	0.0*	0.0	0.0	0.5	10.0	10.5	0.5	11.1
Atlatl (2)	1.0	0.5	0.0	0.0	0.0	0.0	0.5	7.0	7.5	0.5	7.9
Atlatl (3)	0.0	2.0	0.0	0.0	0.0	0.0	2.0	18.0	20.0	2.1	21.2
Total	1.0	3.0	0.0	0.0	0.0	0.0	3.0	35.0	38.0	3.2	40.2
Mean	0.3	1.0	0.0	0.0	0.0	0.0	1.0	11.6	12.6	1.1	13.4
Ball (1)	0.0	9.0	3.0	0.0	0.0	0.0	12.0	24.0	36.0	13.0	38.9
Ball (2)	0.0	16.5	1.0	0.0	0.0	0.0	17.5	23.0	40.5	18.9	43.7
Ball (3)	0.0	27.5	1.0	0.0	0.0	0.0	28.5	17.0	45.5	30.8	49.1
Total	0.0	53.0	5.0	0.0	0.0	0.0	58.0	64.0	122.0	62.6	131.7
Mean	0.0	17.6	1.6	0.0	0.0	0.0	19.3	21.3	40.6	20.8	43.9
Sling (1)	0.0	10.0	0.5	1.0	0.0	0.0	10.5	10.0	21.5	11.3	23.0
Sling (2)	1.0	0.5	0.0	0.0	0.0	0.0	0.5	20.0	20.5	0.5	21.9
Sling (3)	0.0	8.0	0.0	0.0	0.0	0.0	8.0	7.0	15.0	8.6	16.0
Total	1.0	18.5	0.5	1.0	0.0	0.0	19.0	37.0	57.0	20.5	60.9
Mean	0.3	6.2	0.2	0.3	0.0	0.0	6.3	12.3	19.0	6.8	20.3

Note: All values have been rounded to first decimal.

Dart/Atlatl

When throwing the dart, Volunteer #3's accuracy scores throwing the dart barehanded steadily decreased throughout the three sessions. However, her distance score increased slightly towards the end of the experiment, indicating possible improvement.

When using the atlatl, Volunteer #3's accuracy score increased over the three sessions, although it never achieved the same accuracy as the hand-thrown dart. Her distance initially matched that of the dart, decreased below that of the dart in the second session, and then increased to above the dart’s distance in the third session. The atlatl’s mean distance was also slightly greater than that of the hand-thrown dart.

Ball/Sling

Volunteer #3’s accuracy when throwing the ball barehanded increased steadily over the three sessions. Her distance decreased steadily over the three sessions, although her composite score increased over the same time period.

Volunteer #3’s accuracy with the sling started high but decreased over the three sessions. Her accuracy decreased sharply in the second session and then increased in the third session, although this increase never reached the same score as the first session. Her distance score decreased overall, first increasing in the second session and then decreasing notably in the third session to below what it had been in the first session. Her distance scores were consistently below that of the hand-thrown ball. However, she was able to score on the target from 5 meters further away than she was able to do with the hand-thrown ball.

This volunteer appears to have disproven the second hypothesis while supporting the third but provides insufficient data for the first hypothesis. The atlatl is the less accurate of the two weapons in her scores. The sling appears to have the greater effective distance range, with higher distance scores and an ability to score more points from farther distance markers. One hour of practice time for each weapon does not provide sufficient data to state whether the atlatl or sling is more quickly learned as judged by composite scores, meaning the first hypothesis cannot be supported or disproven.

Volunteer #4

Volunteer #4 (Table 4), whose arm measurements fell into the middle of the range among the volunteers, claimed no exceptional athletic ability or prior experience with either weapon.

Table 4. Volunteer #4: Forearm 43.1 cm, Arm 86.1 cm

Session	Practice (Hours)	Accuracy Throws 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Total (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)
Dart (1)	0.0	0.5	0.0	0.0	0.0	0.0	0.5	5.0	5.5	0.5	5.7
Dart (2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	0.0	10.3
Dart (3)	0.0	8.0	0.0	0.0	0.0	0.0	8.0	10.0	18.0	8.2	18.5
Total	0.0	8.5	0.0	0.0	0.0	0.0	8.5	25.0	33.5	8.8	34.5
Mean	0.0	2.8	0.0	0.0	0.0	0.0	2.8	8.3	11.2	2.9	11.5
Atlatl (1)	0.0	9.0	0.0*	0.0	0.0	0.0	9.0	7.0	16.0	9.3	16.5
Atlatl (2)	1.0	0.0	0.5	0.0	0.0	0.0	0.5	7.0	7.5	0.5	7.7
Atlatl (3)	0.0	7.0	0.0	0.0	0.0	0.0	7.0	12.5	19.5	7.2	20.1
Total	1.0	16.0	0.5	0.0	0.0	0.0	16.5	26.5	43.0	17.0	44.3
Mean	0.3	5.3	0.2	0.0	0.0	0.0	5.5	8.8	14.3	5.7	14.8
Ball (1)	0.0	12.0	2.0	0.0	0.0	0.0	14.0	15.0	29.0	14.4	29.9
Ball (2)	0.0	21.0	0.0	0.0	0.0	0.0	21.0	12.0	33.0	21.6	34.0
Ball (3)	0.0	15.5	0.0	0.0	0.0	0.0	15.5	12.5	28.0	16.0	28.8
Total	0.0	48.5	2.0	0.0	0.0	0.0	50.5	39.5	90.0	52.0	92.7
Mean	0.0	16.2	0.6	0.0	0.0	0.0	16.8	13.2	30.0	17.3	30.9
Sling (1)	0.0	1.0	0.0	0.0	0.0	0.0	1.0	9.0	10.0	1.0	10.3
Sling (2)	0.0	0.5	0.0	0.0	0.0	0.0	0.5	5.0	5.5	0.5	5.7
Sling (3)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	0.0	3.1
Total	0.0	1.5	0.0	0.0	0.0	0.0	1.5	17.0	18.5	1.5	19.1
Mean	0.0	0.5	0.0	0.0	0.0	0.0	0.5	5.6	6.2	0.5	6.4

Note: All values have been rounded to first decimal.

Dart/Atlatl

Volunteer #4's accuracy with the hand-thrown dart started low in the first session, decreased to zero, and then increased dramatically in the third session. Her distance increased in the second session and then remained the same in the third session. Her composite score increased consistently over the three sessions.

When Volunteer #4 used the atlatl, her accuracy scores with the atlatl remained above those of the dart for the first two sessions. However, the overall trend was a decrease in accuracy similar to that of the dart. Her mean accuracy score was greater than that of the barehanded dart throw. Her distance also consistently increased, but it was below the distance score of the hand-thrown dart in the second session. Her mean distance score was slightly greater than that of the hand-thrown dart. A notable occurrence is that she was able to score on the target from 5 meters farther away with the atlatl than the barehanded dart throw.

Ball/Sling

Volunteer #4's accuracy with the hand-thrown ball started moderately high, increased in the second session, then decreased in the third session to slightly above where it had begun in the first session. Her distance started high, decreased in the second session, and increased slightly in the third session. The overall trend for her distance was a decrease over the three sessions.

Volunteer #4's accuracy with the sling decreased steadily over time, and neither the individual scores nor the mean score approached the accuracy scores of the ball. The same is true of her distance, which also steadily decreased over the three sessions. Her composite score reflects the decrease over time. Since she did not practice at all with the sling, no link between her scores and practice times could be found.

Volunteer #4's experience supported the second hypothesis while disproving the third. The atlatl was the more accurate weapon, while the sling had inferior accuracy and range compared to the atlatl. As she was unable to practice extensively with both weapons, no conclusions can be drawn about any connection between practice time and skill acquisition, and the first hypothesis cannot be supported or disproven.

Volunteer #5

Volunteer #5 (Table 5) possessed the second longest arm and forearm measurements and claimed no exceptional athletic ability or prior experience with either weapon.

Table 5. Volunteer #5: Forearm 46.7 cm, Arm 88.6 cm

Session	Practice (Hours)	Accuracy Throw 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Total (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)
Dart (1)	0.0	4.5	0.5	0.0	0.0	0.0	5.0	18.0	23.0	4.8	21.9
Dart (2)	0.0	10.0	5.0	0.0	0.0	0.0	15.0	20.0	35.0	14.3	33.3
Dart (3)	0.0	21.0	4.0	0.0	0.0	0.0	25.0	18.0	43.0	23.8	40.9
Total	0.0	35.5	9.5	0.0	0.0	0.0	45.0	56.0	101.0	42.8	96.1
Mean	0.0	11.8	3.2	0.0	0.0	0.0	15.0	18.6	33.6	14.3	32.0
Atlatl (1)	0.0	10.5	8.5*	0.0	0.0	0.0	19.0	27.0	46.0	18.1	43.7
Atlatl (2)	1.0	15.0	3.5	0.0	0.0	0.5	19.0	27.0	46.0	18.1	43.7
Atlatl (3)	0.0	12.5	0.0	0.0	0.5	6.5	19.5	33.5	53.0	18.5	50.3
Total	1.0	38.0	12.0	0.0	0.5	7.0	57.5	87.5	145.0	54.6	137.7
Mean	0.3	12.6	4.0	0.0	0.2	2.3	19.2	29.2	48.3	18.2	45.9
Ball (1)	0.0	13.5	0.0	1.0	0.0	0.0	13.5	30.0	44.5	13.5	44.5
Ball (2)	0.0	26.5	4.0	0.5	0.0	0.0	31.0	30.0	61.0	31.0	61.0
Ball (3)	0.0	33.0	11.0	1.0	0.0	0.0	45.0	25.0	70.0	45.0	70.0
Total	0.0	73.0	15.0	2.5	0.0	0.0	89.5	85.0	175.5	89.5	175.5
Mean	0.0	24.3	3.0	0.8	0.0	0.0	29.8	28.3	58.5	29.8	58.5
Sling (1)	0.0	1.0	0.0	0.0	0.5	0.0	1.5	20.0	21.5	1.5	21.5
Sling (2)	1.0	1.0	0.0	0.5	0.0	0.5	2.0	30.0	32.0	2.0	32.0
Sling (3)	0.0	3.5	0.0	0.0	0.0	0.0	3.5	30.0	33.5	3.5	33.5
Total	1.0	5.5	0.0	0.5	0.5	0.5	7.0	80.0	87.0	7.0	87.0
Mean	0.3	1.8	0.0	0.2	0.2	0.2	2.3	26.6	29.0	2.3	29.0

Note: All values have been rounded to first decimal.

Dart/Atlatl

Volunteer #5's accuracy when hand-throwing the dart steadily increased over the three sessions, although most of the increase came from throws at the 5-meter distance marker. His distance increased in the second session and then decreased in the third session to what it had been in the first session.

When Volunteer #5 used the atlatl, his accuracy remained nearly the same over all three sessions, increasing slightly in the third session. However, its accuracy remained higher than that of the dart until the third session, and its mean accuracy was greater than the mean accuracy of the hand-thrown dart. One notable point is that, in the third session, he was able to score hits on the target, including one 6-point strike from the 25-meter distance marker. This is something only Volunteer #1, the only other male volunteer, was able to do. His mean accuracy score, composite score, and distance score were all higher than those of the dart, particularly his mean distance score.

Ball/Sling

When Volunteer #5 threw the ball unassisted, his composite score and accuracy score increased steadily over the three sessions, but his distance decreased between the second and third sessions. His accuracy in particular increased more than threefold between the first and third sessions. However, most of the accuracy score came from throws at the 5-meter distance marker, and he was unable to score hits on the target from more than 15 meters away.

Volunteer #5's accuracy with the sling steadily increased with time, although it never reached the ball's accuracy. The distance increased in the second session but then held steady in the third session. The sling's distance matched that of the ball in the second session and surpassed it in the third session.

Volunteer #5's experiences appear to support the second hypothesis while disproving the third. The atlatl was more accurate than the sling and possessed a greater range. However, as he was only able to practice for one hour with each weapon, no firm conclusions can be drawn about whether the atlatl or the sling is more strongly affected by practice time.

Group

Overall, the volunteers' experiences support the hypotheses that the atlatl would be more quickly mastered as measured by accuracy and that the sling would have the greater range of the two weapons (Table 6). However, there is insufficient data about practice times to support or disprove whether the atlatl is more quickly learned than the sling.

Table 6 shows the mean of all volunteers' scores for a clearer picture of how they performed as a group at any given instance. All values have been rounded to the first decimal place.

There is insufficient data to firmly support or disprove whether the atlatl is more quickly learned, as judged by composite scores and practice time. While one volunteer's experience disproves this hypothesis, there is insufficient data from the other volunteers to support or disprove this hypothesis.

The data supports the hypothesis that the atlatl is the more accurate of the two force multipliers. The mean accuracy score for the atlatl across all volunteers was nearly twice that of the sling. Mean accuracy scores for the atlatl, while higher than those of the sling, experienced an overall slight decrease over the course of the experiment and decreased notably in the second session. The same pattern is seen in the adjusted accuracy scores.

Table 6. Means Table: Forearm 45 cm, Arm 87.1 cm

Session	Practice (Hours)	Accuracy Throws 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Total (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)
Dart (1)	0.0	8.4	0.6	0.0	0.0	0.0	9.0	15.4	24.4	9.0	24.0
Dart (2)	0.0	4.9	1.4	0.1	0.0	0.0	6.4	17.8	24.2	6.4	23.6
Dart (3)	0.0	11.7	1.9	0.1	0.0	0.0	13.7	17.4	31.1	13.5	30.5
Total	0.0	25.0	3.9	0.2	0.0	0.0	29.1	50.6	79.7	29.0	78.1
Mean	0.0	8.3	1.3	0.1	0.0	0.0	9.7	16.9	26.6	9.6	26.0
Atlatl (1)	0.0	7.3	3.4	0.0	0.0	0.0	10.7	16.0	26.7	10.7	25.9
Atlatl (2)	2.2	3.3	2.4	0.0	0.0	0.2	5.9	17.2	23.1	5.4	21.8
Atlatl (3)	1.6	6.4	0.3	0.9	0.1	1.3	9.0	19.3	28.3	8.8	28.3
Total	3.8	17.0	6.1	0.9	0.1	1.5	25.6	52.5	78.1	24.9	76.0
Mean	1.3	5.7	2.0	0.3	0.0	0.5	8.5	17.5	26.0	8.3	25.3
Ball (1)	0.0	15.3	3.8	0.8	0.3	0.2	20.2	31.3	51.7	21.1	53.1
Ball (2)	0.0	22.1	2.6	0.3	0.1	1.9	27.0	23.4	50.4	28.9	52.9
Ball (3)	0.0	34.7	4.8	2.3	2.7	0.1	44.6	23.4	67.0	45.4	67.7
Total	0.0	72.1	11.2	3.4	3.1	2.2	91.8	78.1	169.1	95.3	173.7
Mean	0.0	24.0	3.7	1.1	1.0	0.7	30.6	26.0	56.4	31.7	57.9
Sling (1)	0.0	3.6	0.3	1.4	0.1	0.0	5.2	18.8	24.2	5.4	24.3
Sling (2)	1.1	2.1	0.2	0.3	1.0	0.1	3.7	22.2	25.9	3.8	26.1
Sling (3)	1.6	4.2	0.2	0.0	0.0	0.0	4.4	15.0	19.4	4.6	19.6
Total	2.7	9.9	0.7	1.7	1.1	0.1	13.3	56.0	79.5	13.8	70.0
Mean	0.9	3.3	0.2	0.6	0.4	0.0	4.4	18.7	23.2	4.6	23.3

Note: All values have been rounded to first decimal.

The sling's mean accuracy score, while lower than that of the atlatl, also experienced a decrease over the course of the experiment. Its most notable decrease occurred in the second session. While the sling’s mean accuracy increased in the third session, it did not return to the accuracy score of the first session, indicating that the volunteers had not yet mastered the sling.

The third hypothesis, which stated that the sling would have the greater range, is also supported by the mean scores. The sling’s mean distance was slightly greater than that of the atlatl, as were its mean scores for the first two sessions.

The sling’s distance score was consistently shorter than golf balls thrown barehanded. While both the sling and the golf balls were able to score points on the target from 25 meters, three of the four instances of this were barehanded throws. The distance for the sling, when averaged across all of the volunteers and all of the testing sessions, was considerably less than the mean distance for the barehanded golf ball throw across all sessions. The sling here cannot be judged to be an improvement on a hunter's range for throwing stones.

The atlatl's mean distance score was consistently higher than the barehanded dart throws. Not only is the atlatl's mean distance greater, but the atlatl was able to score on the target from the farthest distance marker, which the dart could not do. The atlatl here is a clear improvement over throwing the dart barehanded on range alone, adding at its maximum several meters' advantage to a hunter's potential maximum striking range with only minimal if any practice.

The atlatl also consistently performed better than the sling when judged by the composite score, which combined distance and accuracy scores. The atlatl also consistently performed better than the sling when judged by the overall raw score, which combined range and accuracy. The mean composite score for the atlatl when judged over all of the testing sessions was slightly higher than that of the sling. This difference was seen even in the first session, where the sling's mean composite score across all of the volunteers was slightly less than that of the atlatl. This difference increased with time, ending with the atlatl's mean composite score much higher than that of the sling.

Increased forearm and arm length were weakly linked to an increase in distance and composite scores. But with both the atlatl and the sling, accuracy decreased when plotted against increasing forearm length. Upon closer analysis, the increase in composite scores with longer arm and forearm measurements appears to come from an increase in distance, which may depend on the larger mechanical advantage that these volunteers possessed.

The mean accuracy scores for both force multipliers decreased over the course of the testing sessions. Only one volunteer showed consistent improvement with the sling and the atlatl, but this was an exception.

CHAPTER #6: DISCUSSION

To reiterate, there were three hypotheses tested by this experiment:

1) The atlatl would be mastered more quickly than the sling, as measured by composite scores and practice time.

2) The atlatl would be a more accurate weapon than the sling.

3) The sling would have a longer effective range than the atlatl.

The results of each volunteer's individual tests for the three hypotheses (Table 7) support the hypothesis that the atlatl would be the more accurate weapon and the hypothesis that the sling would have the longer range. However, the hypothesis that the atlatl would be more quickly learned, as measured by composite scores, could not be supported or disproven. Several other patterns, such as volunteers' scores decreasing in the second session and then improving in the third session or their throwing farther in the accuracy trials than in the distance trials, were unexpected results that require closer examination.

It was clear that the volunteers even after their sessions were still novices with their weapons. This was not unexpected due to the brevity of the experiment, but their slow progress may have been partly due to a lack of practice. Only one volunteer invested large amounts of practice time in both weapons, while the rest were only able to practice for an hour or unable to practice at all. This lack of practice means that, in spite of the atlatl having greater composite scores, no appreciable conclusions about learning times can be drawn from this dataset. There is simply insufficient data to support or disprove the first hypothesis. A longer experiment may remedy this problem.

Table 7. Hypothesis Support Summary

Hypothesis #1			Hypothesis #2			Hypothesis #3		
Atlatl Composite	Sling Composite	(1 = Support)	Atlatl Accuracy	Sling Accuracy	(1 = Support)	Atlatl Distance	Sling Distance	(1 = Support)
33.0	41.5	0	7.0	6.5	1	26	35	1
39.0	41.0	0	9.0	6.0	1	30	35	1
17.0	24.0	0	7.0	4.0	1	10	20	1
28.0	26.5	1	18.0	6.5	1	10	20	1
15.5	30.5	0	0.5	9.5	0	15	21	1
32.0	21.5	1	9.5	6.5	1	22.5	15	0
10.5	21.5	0	0.5	10.5	0	10	10	0
7.5	20.5	0	0.5	0.5	0	7	20	1
20.0	15.0	1	2.0	8.0	0	18	7	0
16.0	10.0	1	9.0	1.0	1	7	9	1
7.5	5.5	1	0.5	0.5	0	7	5	0
19.5	3.0	1	7.0	0.0	1	12.5	3	0
46.0	21.5	1	19.0	1.5	1	27	20	0
46.0	32.0	1	19.0	2.0	1	27	30	1
53.0	33.5	1	19.5	3.5	1	35	30	0
TRUE		9 of 15	TRUE		10 of 15	TRUE		8 of 15
Hypothesis supported?		Yes	Hypothesis supported?		Yes	Hypothesis supported?		Yes

While the atlatl was more accurate than the sling, both weapons experienced an unexpected overall decrease in accuracy. Although volunteers were able to score points on the target from greater and greater distances, their accuracy decreased. This happened while the hand-thrown dart and ball scores increased over the course of the experiment. Fatigue may have been a factor, particularly the scores made from the farther distance markers. The volunteers each had to perform 200 throws of varying types over the course of one testing session, which normally lasted approximately one to one and a half hours. As explained before, they had to start at the closest distance marker and move out to the farthest marker over the testing session. If fatigue was a factor in their ability to hit the target accurately or throw a great distance, this would decrease their accuracy scores at greater distance markers. This would also affect their distance scores, which were performed after the accuracy trials and thus when the volunteers would be most affected by fatigue. Further experimentation should take this into account.

The sling had a greater distance range than the atlatl in eight of the fifteen distance throws and a greater mean distance than the atlatl for the group overall. However, the sling's distance range tended to decrease over the three sessions, whereas the atlatl's distance range increased over the three sessions. This indicates a lack of mastery of the sling.

Another indication of the volunteers' lack of mastery was the fact that they regularly threw longer distances during the accuracy trials than they did during the designated distance throw (Table 8). This was possible, of course, only when they missed the target completely. These distances did not contribute to a volunteer's score at all. However, they occurred often enough to be recorded and taken into consideration.

Table 8. Non-Designated Distances

Volunteer	Session	Weapon	Total Practice	Distance
#5	1	Dart	0.0	19.0
#1	3	Dart	0.0	40.0
#1	1	Atlatl	0.0	30.0
#2	1	Atlatl	0.0	24.0
#3	2	Atlatl	1.0	15.0
#1	3	Atlatl	16.0	40.0
#3	3	Atlatl	1.0	20.0
#4	1	Ball	0.0	18.0
#2	3	Ball	0.0	45.0
#3	3	Ball	0.0	20.0
#4	3	Ball	0.0	13.0
#2	1	Sling	0.0	25.0
#2	3	Sling	0.0	20.0
#3	3	Sling	1.0	15.0
#4	3	Sling	0.0	5.0

All distances have been rounded to nearest whole meter.

Because these throws missed their targets, they demonstrate that the volunteers' skills were still at novice levels. However, these unintended distance throws do demonstrate the possible ranges of the atlatl and the sling once mastered. If these distance throws had been taken into account, then the atlatl's advantage over the hand-thrown dart would have increased greatly, and its mean distance for all five volunteers would have increased by several meters over the three sessions. The sling's mean distance, while still less than that of the hand-thrown ball, also would have improved with the inclusion of these accidental distances. Although unintended, they do show the potential ranges of the weapons once mastered.

The volunteers with the highest accuracy and composite scores were not necessarily the ones who showed the greatest improvement over the three sessions. Of the five volunteers, Volunteer #5 was the most accurate with the atlatl both before and after his scores were adjusted, in addition to having the highest composite scores with and without adjustment. This volunteer consistently improved with the atlatl in both accuracy and distance. However, the volunteer whose adjusted accuracy and adjusted composite scores improved the most was Volunteer #3, in spite of having the second lowest accuracy scores before and after adjustment. In the case of the sling, Volunteer #5 showed the greatest improvement in accuracy, although Volunteer #2 scored the highest points in accuracy.

The second session was when scores were often the lowest of the whole experiment. This slump is strongly believed to result from inclement weather with high winds. Future experiments are encouraged to control for this by finding a suitable indoors testing location.

The difference between the two force multipliers' mean scores may be partly explained by the skills needed to use each force multiplier. The sling requires a degree of split-second timing, muscle memory, and other factors that a novice is unlikely to develop in a short time. The personal experience of the author, though not included in the final data, indicated that more than 60 hours of practice were needed to strike a target 70% of the time. As the volunteers did not practice much, their skills with the sling did not improve during the experiment.

The atlatl has several factors that may make its adoption easier than the sling. Its throwing motion overall is more straightforward and requires less split-second timing to send the dart to its target. Modern adults have often become proficient in its use. During 25 hours of practice, the author was able to reliably strike a target slightly larger than the bullseye at a distance of 10 meters, although this data was not used in the final analysis. The atlatl would appear to require less time to master than the sling, but as the volunteers did not practice much, no firm conclusions can be drawn.

Whittaker and Kamp have some insight about the atlatl's learning curve (Whittaker & Kamp, 2006) that might be extended to the sling. According to Whittaker and Kamp, the amount of practice a competitor invests has a greater impact on scores than age or gender. They note that the greatest increase in competition scores occurred after several years (Whittaker & Kamp, 2006), whereas age only determines a minimum age before an atlatl user is able to become proficient. What was observed in the present experiment's data for the atlatl may be the ordinary variation of scores among beginners and reflects that gender and stature had little to no impact on scores. The atlatl and sling would no doubt have shown more dramatic improvement given more practice time and a longer experiment.

Whittaker and Kamp's study also notes that, prior to a certain developmental age, children are unable to effectively use the atlatl. If this is extended to the sling, this may prove to be of interest to forensic anthropologists and archaeologists alike. It may be that if children or adolescents of a culture that used the sling or the atlatl began to truly develop their skills at a certain developmental or skeletal age, there will be skeletal alterations reflecting this heavy use and its effect on their development. This can indicate the use of the sling or the atlatl even if the weapons themselves cannot be found.

However, the atlatl does not have as great a leveling effect for people of different statures as Whittaker and Kamp believe. Body size, particularly arm length, had some impact on the volunteers' success with both force multipliers. Their stature seemed to affect distance throws the most, which in turn somewhat affected their unadjusted composite scores. The volunteer who consistently had the highest composite scores with the atlatl had only the second longest forearm. The volunteer with the longest forearm came in second in composite scores. The sling saw similar results, with the top two composite scores belonging to the two volunteers with the longest arms. While the relationship is not a perfect one, stature does appear to affect the range of the force multiplier weapons.

Of all possible variables, athletic ability appears to affect accuracy and distance scores the most. Volunteer #2, who had the shortest arms and forearms but also possessed years of athletic experience, won the prize of food in all three testing sessions by having the highest adjusted composite scores. Although none of the volunteers had prior experience with the weapons, prior athletic experience apparently was a greater advantage than other factors under consideration, including gender and stature.

The volunteers' collective experience indicates that there may have been other forces behind the initial adoption and continued use of these weapons than ease of learning and use. The volunteers had a difficult time learning the basics of operating the atlatl and sling, and in some notable cases performed better when throwing darts or balls unassisted. While the increase in distance due to the technology may have been an incentive, there may also have been cultural factors, such as the status or prestige awarded a particularly skilled user or an excellent hunter, driving the initial adoption of challenging weapon technology. An abundance of materials, such as wood of suitable flexibility and length for atlatl darts, or the scarcity thereof may also explain why these weapons developed and persisted in different geographical areas and also why they may have later fallen out of favor. The bow and arrow supplanting the atlatl may have been driven by a scarcity of suitable materials as well as an improvement in technology that allowed for its use in much closer quarters.

This experiment was designed to minimize error in data collection, but there were unexpected developments in spite of this. Some of the factors could not be easily controlled, such as the weather, which may have contributed to the notable decrease in scores across the second session. Others, such as flaws in the atlatl design, were noted and worked around to minimize the impact on the experiment. The volunteers themselves represented unknown factors that may have affected their scores, such as one volunteer having had experience playing softball or volunteers' statures making a difference in their scores. These issues were compensated for as much as was possible to reduce the possibility of errors in the experiment. Recommendations for future experiments would include choosing an atlatl design that was not as prone to breaking or reworking Hrdlicka's atlatl design to compensate for its weakness (Hrdlicka, 2002a) and finding an indoors location for practice and testing to avoid the weather.

Two issues that could not easily be accounted for were the limited size of the volunteer pool and the length of their practice with each weapon. While five volunteers are acceptable for a pilot study and proof of concept, a much larger pool would be preferable for a more in-depth experiment. Similarly, the length of the experiment should be increased in future studies, both to encourage the volunteers to continue practicing and to better understand the development of their skills through time.

A solution to both issues would be to create a club centered on the force multiplier weapons in question. A large volunteer pool consisting of people who had practiced extensively, novices, and serious users would be beneficial. By locating or even starting a club for both weapons, thereby drawing a larger pool of volunteers for future experiments, the learning curve could be better studied. Their membership could even be used to track their progress prior to the beginning of a specific experiment by logging their scores, the farthest distance they could hit a bullseye target from and how accurately, and their overall variation from day to day. If this pool includes serious hunters, there may be a need for several different ways to track and score their progress, as being able to successfully hunt prey is a different measure of success than being able to hit a target at a set distance. Having a wider pool of volunteers to draw from at varying points of proficiency would more accurately track the time investment needed to master both weapons and the variation of scores that might affect trends seen in the data.

CHAPTER #7: CONCLUSIONS

This study is proof of concept for the testing of force multiplier weapons and it did test its hypotheses. While a longer and more in-depth study would be required for deeper analysis, this study stands on its own as preliminary research.

Of the three hypotheses, the first, that the atlatl would be more quickly learned as measured by composite scores and time, could not be supported or disproven due to insufficient data. The second hypothesis, which stated that the atlatl would be more accurate than the sling, was clearly supported by the data. The third hypothesis, which stated the sling had the greater range, was also supported by the data.

The testing sessions also had unexpected results that may be explored in greater depth in the future. Both weapons' accuracy decreased over the course of the three testing sessions, which appears to indicate a lack of mastery during the early stages of training. However, the ranges of both weapons increased significantly over the course of the experiment, which contributed greatly to increased composite scores. While greater stature contributed to greater range, longer limb measurements were slightly negatively correlated with accuracy scores. Prior experience with similar athletic actions appeared to contribute more to any volunteer's scores than did stature.

The relatively small investment in practice time that the volunteers were able to give does not necessarily represent the practice and experimentation that would have initially gone into the skill acquisition related to these two force multipliers. A longer and more in-depth experiment with a larger pool of volunteers may answer some of the questions raised by this study.

This brief study is both able to stand on its own and serves as proof of concept for testing prehistoric force multiplier weapons. Further research involving the atlatl and the sling is necessary to more fully understand the forces at work in the acquisition of weapon skills.

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APPENDIX

MASTER DATA TABLES

Volunteer	Session	Weapon	Practice	Accuracy Throws						Distance	Composite	Adjusted	Adjusted	Forearm (Cm)
			Hours	5m	10m	15m	20m	25m	Acc.	Throw	Score	Accuracy	Composite	
				(pts)	(pts)	(pts)	(pts)	(pts)	(pts)	(pts = m)	(pts)	(pts)	(pts)	
#1	1	Dart	0.0	10.5	0.5	0.0	0.0	0.0	11.0	25.0	36.0	9.2	30.2	52.9
#2	1	Dart	0.0	14.5	2.0	0.0	0.0	0.0	16.5	19.0	35.5	18.0	38.7	40.6
#3	1	Dart	0.0	12.0	0.0	0.0	0.0	0.0	12.0	10.0	22.0	12.7	23.3	41.8
#4	1	Dart	0.0	0.5	0.0	0.0	0.0	0.0	0.5	5.0	5.5	0.5	5.7	43.1
#5	1	Dart	0.0	4.5	0.5	0.0	0.0	0.0	5.0	18.0(19.0)	23.0	4.8	21.9	46.7
Mean	1	Dart	0.0	8.4	0.6	0.0	0.0	0.0	9.0	15.4 (15.6)	24.4	9.0	24.0	45.0
#1	2	Dart	0.0	3.0	0.0	0.0	0.0	0.0	3.0	30.0	33.0	2.5	27.7	52.9
#2	2	Dart	0.0	9.0	2.0	0.5	0.0	0.0	11.5	19.0	30.5	12.5	33.2	40.6
#3	2	Dart	0.0	2.5	0.0	0.0	0.0	0.0	2.5	10.0	12.5	2.7	13.3	41.8
#4	2	Dart	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	0.0	10.3	43.1
#5	2	Dart	0.0	10.0	5.0	0.0	0.0	0.0	15.0	20.0	35.0	14.3	33.3	46.7
Mean	2	Dart	0.0	4.9	1.4	0.1	0.0	0.0	6.4	17.8	24.2	6.4	23.6	45.0
#1	3	Dart	0.0	10.5	1.5	0.5	0.0	0.0	12.5	26.0(40.0)	38.5	10.5	32.3	52.9
#2	3	Dart	0.0	17.0	4.0	0.0	0.0	0.0	21.0	20.0	41.0	22.9	44.7	40.6
#3	3	Dart	0.0	2.0	0.0	0.0	0.0	0.0	2.0	13.0	15.0	2.1	15.9	41.8
#4	3	Dart	0.0	8.0	0.0	0.0	0.0	0.0	8.0	10.0	18.0	8.2	18.5	43.1
#5	3	Dart	0.0	21.0	4.0	0.0	0.0	0.0	25.0	18.0	43.0	23.8	40.9	46.7
Mean	3	Dart	0.0	11.7	1.9	0.1	0.0	0.0	13.7	17.4(20.2)	31.1	13.5	30.5	45.0
#1	1	Atlatl	0.0	7.0	0.0	0.0	0.0	0*	7.0	26.0(30.0)	33.0	5.9	27.6	52.9
#2	1	Atlatl	0.0	9.5	8.5	0.0	0.0	0.0	18.0	10.0(24.0)	28.0	19.6	30.5	40.6
#3	1	Atlatl	0.0	0.5	0.0	0*	0.0	0.0	0.5	10.0	10.5	0.5	11.1	41.8
#4	1	Atlatl	0.0	9.0	0*	0.0	0.0	0.0	9.0	7.0	16.0	9.3	16.5	43.1
#5	1	Atlatl	0.0	10.5	8.5*	0.0	0.0	0.0	19.0	27.0	46.0	18.1	43.7	46.7
Mean	1	Atlatl	0.0	7.3	3.4	0.0	0.0	0.0	10.7	16.0(19.6)	26.7	10.7	25.9	45.0
#1	2	Atlatl	8.0	0.5	8.0	0.0	0.0	0.5	9.0	30.0	39.0	7.6	32.8	52.9
#2	2	Atlatl	0.0	0.5	0.0	0.0	0.0	0.0	0.5	15.0	15.5	0.5	16.9	40.6
#3	2	Atlatl	1.0	0.5	0.0	0.0	0.0	0.0	0.5	7.0(15.0)	7.5	0.5	7.9	41.8
#4	2	Atlatl	1.0	0.0	0.5	0.0	0.0	0.0	0.5	7.0	7.5	0.5	7.7	43.1
#5	2	Atlatl	1.0	15.0	3.5	0.0	0.0	0.5	19.0	27.0	46.0	18.1	43.7	46.7
Mean	2	Atlatl	2.2	3.3	2.4	0.0	0.0	0.2	5.9	17.2(18.8)	23.1	5.4	21.8	45.0
#1	3	Atlatl	8.0	6.5	0.5	0.0	0.0	0.0	7.0	10.0(40.0)	17.0	5.9	15.1	52.9
#2	3	Atlatl	0.0	4.0	1.0	4.5	0.0	0.0	9.5	22.5	32.0	10.4	34.9	40.6
#3	3	Atlatl	0.0	2.0	0.0	0.0	0.0	0.0	2.0	18.0(20.0)	20.0	2.1	21.2	41.8
#4	3	Atlatl	0.0	7.0	0.0	0.0	0.0	0.0	7.0	12.5	19.5	7.2	20.1	43.1
#5	3	Atlatl	0.0	12.5	0.0	0.0	0.5	6.5	19.5	33.5	53.0	18.5	50.3	46.7
Mean	3	Atlatl	1.6	6.4	0.3	0.9	0.1	1.3	9.0	19.3(25.7)	28.3	8.8	28.3	45.0

Note: An asterisk (*) indicates where a volunteer changed to a metal screw on his or her atlatl instead of a wooden peg. Parenthetical distances were achieved during target throws.

Volunteer	Session	Weapon	Practice Hours	Accuracy Throws 5m (pts)	10m (pts)	15m (pts)	20m (pts)	25m (pts)	Acc. (pts)	Distance Throw (pts = m)	Composite Score (pts)	Adjusted Accuracy (pts)	Adjusted Composite (pts)	Arm (cm)
#1	1	Ball	0.0	17.0	1.5	1.0	0.5	1.0	21.0	47.5	68.5	18.5	60.3	100.9
#2	1	Ball	0.0	25.0	12.5	2.0	1.0	0.0	40.5	40.0	80.5	46.2	91.8	77.5
#3	1	Ball	0.0	9.0	3.0	0.0	0.0	0.0	12.0	24.0	36.0	13.0	38.9	82.4
#4	1	Ball	0.0	12.0	2.0	0.0	0.0	0.0	14.0	15.0(18.0)	29.0	14.4	29.9	86.1
#5	1	Ball	0.0	13.5	0.0	1.0	0.0	0.0	13.5	30.0	44.5	13.5	44.5	88.6
Mean	1	Ball	0.0	15.3	3.8	0.8	0.3	0.2	20.2	31.3(31.9)	51.7	21.1	53.1	87.1
#1	2	Ball	0.0	4.5	2.0	0.5	0.0	0.0	7.0	25.0	32.0	6.2	28.2	100.9
#2	2	Ball	0.0	42.0	6.0	0.5	0.5	9.5	58.5	27.0	85.5	66.7	97.5	77.5
#3	2	Ball	0.0	16.5	1.0	0.0	0.0	0.0	17.5	23.0	40.5	18.9	43.7	82.4
#4	2	Ball	0.0	21.0	0.0	0.0	0.0	0.0	21.0	12.0	33.0	21.6	34.0	86.1
#5	2	Ball	0.0	26.5	4.0	0.5	0.0	0.0	31.0	30.0	61.0	31.0	61.0	88.6
Mean	2	Ball	0.0	22.1	2.6	0.3	0.1	1.9	27.0	23.4	50.4	28.9	52.9	87.1
#1	3	Ball	0.0	48.0	8.0	4.5	8.0	0.0	68.5	37.5	106.0	60.3	93.3	100.9
#2	3	Ball	0.0	49.5	4.0	6.0	5.5	0.5	65.5	25.0(45.0)	85.5	74.7	97.5	77.5
#3	3	Ball	0.0	27.5	1.0	0.0	0.0	0.0	28.5	17.0(20.0)	45.5	30.8	49.1	82.4
#4	3	Ball	0.0	15.5	0.0	0.0	0.0	0.0	15.5	12.5(13.0)	28.0	16.0	28.8	86.1
#5	3	Ball	0.0	33.0	11.0	1.0	0.0	0.0	45.0	25.0	70.0	45.0	70.0	88.6
Mean	3	Ball	0.0	34.7	4.8	2.3	2.7	0.1	44.6	23.4(28.1)	67.0	45.4	67.7	87.1
#1	1	Sling	0.0	6.0	0.5	0.0	0.0	0.0	6.5	35.0	41.5	5.7	36.5	100.9
#2	1	Sling	0.0	0.0	0.5	6.0	0.0	0.0	6.5	20.0(25.0)	26.5	7.4	30.2	77.5
#3	1	Sling	0.0	10.0	0.5	1.0	0.0	0.0	10.5	10.0	21.5	11.3	23.0	82.4
#4	1	Sling	0.0	1.0	0.0	0.0	0.0	0.0	1.0	9.0	10.0	1.0	10.3	86.1
#5	1	Sling	0.0	1.0	0.0	0.0	0.5	0.0	1.5	20.0	21.5	1.5	21.5	88.6
Mean	1	Sling	0.0	3.6	0.3	1.4	0.1	0.0	5.2	18.8(19.8)	24.2	5.4	24.3	87.1
#1	2	Sling	3.5	5.0	0.5	0.5	0.0	0.0	6.0	35.0	41.0	5.3	36.1	100.9
#2	2	Sling	0.0	3.5	0.5	0.5	5.0	0.0	9.5	21.0	30.5	10.8	34.8	77.5
#3	2	Sling	1.0	0.5	0.0	0.0	0.0	0.0	0.5	20.0	20.5	0.5	21.9	82.4
#4	2	Sling	0.0	0.5	0.0	0.0	0.0	0.0	0.5	5.0	5.5	0.5	5.7	86.1
#5	2	Sling	1.0	1.0	0.0	0.5	0.0	0.5	2.0	30.0	32.0	2.0	32.0	88.6
Mean	2	Sling	1.1	2.1	0.2	0.3	1.0	0.1	3.7	22.2	25.9	3.8	26.1	87.1
#1	3	Sling	8.0	3.0	1.0	0.0	0.0	0.0	4.0	20.0	24.0	3.5	21.1	100.9
#2	3	Sling	0.0	6.5	0.0	0.0	0.0	0.0	6.5	15.0(20.0)	21.5	7.4	24.5	77.5
#3	3	Sling	0.0	8.0	0.0	0.0	0.0	0.0	8.0	7.0(15.0)	15.0	8.6	16.0	82.4
#4	3	Sling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0(5.0)	3.0	0.0	3.1	86.1
#5	3	Sling	0.0	3.5	0.0	0.0	0.0	0.0	3.5	30.0	33.5	3.5	33.5	88.6
Mean	3	Sling	1.6	4.2	0.2	0.0	0.0	0.0	4.4	15.0(18.0)	19.4	4.6	19.6	87.1

Note: An asterisk (*) indicates where a volunteer changed to a metal screw on his or her atlatl instead of a wooden peg. Parenthetical distances were achieved during target throws.