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Sling Technology: Towards an understanding of capabilities

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Abstract: *Slings as artifacts have seen relatively little research compared to other primitive weaponry. Yet these simple tools are nearly ubiquitous in their distribution among human societies and in many cases – ranging from Classical Greece and Rome to the Incans and Aztecs at contact – slings played a major role in warfare. Given the importance of the sling to many cultures, it is surprising that its capabilities are so poorly understood. Investigating range and impact effects, this paper critiques previous literature and offers original mathematical modeling.*

Introduction

The sling is known to many Americans only as the weapon of David from the Old Testament. It is the poor man's weapon, the shepherd's weapon, the boy's weapon or even toy. People often consider this artifact, to the extent they consider it at all, to be of little importance in hunting or warfare or indeed culture in general. Yet history shows us that the simple sling has a long record as a recognized weapon of war. Especially in Peru, Europe and the Middle East, the humble sling may have, at times, shaped warfare as much as the bow. As of today, however, the performance of this weapon is poorly understood. Recognizing range and impact as critical components of effectiveness, this paper examines the literature to date before presenting a hypothetical model of sling effectiveness. Finally, citing experiential exercises in sling manufacture and use I undertook, I briefly point a way forward for future archaeological experimentation.

Sling Use and Distribution

The sling's distribution in antiquity was truly worldwide. Means (1919) makes it clear that the sling had a widely distributed pattern of use throughout South America. In Peru the sling was an important military arm and was heavily featured in iconography. In addition, many slings have been preserved in Peruvian contexts and these form most of the world's surviving

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examples. Caches of stones found in hillforts have been interpreted as ammunition stockpiles.

The sling was also encountered in military settings by conquistadores invading Mexico (Means 1919: 317-318). Heizer and Johnson (1952) make it clear that knowledge and use of the sling was widespread among native North Americans at least in the late 1930's. Furthermore, their find in Lovelock Cave provides solid evidence of sling use dating back as far as 2482 +/- 260 years Before Present (B.P).

In the Old World, evidence is even more forthcoming. Aside from historically documented use of slingers in Assyrian, Greek, Judean, Roman and Persian armies (Dohrenwend 2002, Echols 1950)—to name a few—there is archaeological evidence in the form of ammunition caches scattered across Britain (Finney 2006) and almost certainly the hillforts throughout continental Europe as well. Cast lead bullets were manufactured by the Greeks and Romans: these artifacts are an essential component of an excellent analysis of the urban fighting in Olynthos, 348 B.C. (Lee 2001). Reichel (2009) similarly documented a battle at Hamoukar, where both sides used clay sling bullets in the fight over the small city around 3500 B.C. Iconography from the Middle East and Europe frequently shows slings in military contexts or hunting scenes (Korfmann 1973, slinging.org). Dohrenwend (2002: 32) also states that sling use was common among tribal peoples in Asia, especially pastoral peoples and that in Europe the sling has been up until modern times as a shepherd's weapon.

Use has continued in some areas into the present day: slinging is still practiced by Peruvian peoples (Vega and Craig 2009; slinging.org) and slings have been used by Palestinian fighters resisting Israeli occupation as well as guerrilla fighters during the Spanish Civil War (slinging.org). In short, this simple weapon has seen continued use, with only minor variations in form, throughout the world.

Sling Description

Main parts of a sling are the pouch, the retention cord and the release cord. The ammunition can also be considered an essential element, and the design of the sling takes into account the sort of ammunition expected to be used. The basic design of the sling is fairly constant: Two cords of equal length are attached to opposite ends of a pouch that holds the projectile. One cord is designed to be held through the throwing motion (the retention cord), the other (the release cord) to be released at the proper time to open the pouch and launch the projectile. While this central concept is constant, variation is seen in the materials and design of the parts.

A wide variety of materials can be used, but it appears some are more common in antiquity than others. Design requirements for the cords are flexibility, light weight, strength and lack of elasticity (Forsyth). Modern articles from hobbyists list everything from jute, hemp, wool, nylon and leather (Bollinger, Forsyth, Santiago, Tosso 2009). Essentially any fiber technology will do. Either the individual strand may be considered strong enough to act alone or multiple fibers are combined, usually through braiding. Surviving examples are from Peru and a cave in Nevada: settings with excellent preservation conditions. Most examples come from lowland Peru (Means 1919), all are of woven fibers, usually wool. Means also mentions ethnographic descriptions of slings in contact era Mexico, these were made of plant fibers. The find in Lovelock Cave, Nevada—the first prehistoric sling found north of the Rio Grande—was made of "in all probability...twisted Indian Hemp fiber" (Heizer 1952: 142). Design elements include a few options which can be appended onto the cord. Retention cords often had loops intended either to wrap around the wrist or a finger, while release cords might end in a tassel or knot to aid in control (Dohrenwend 2002: 33; Korfmann 1973 37-38).

Material requirements for pouches are much the same as for cords. Strength and flexibility are necessities, and the abrasion created by the projectile's release suggests selection for resistance to this sort of wear-and-tear. Materials match those used for cords and in many cases the same material is used throughout the sling. Means (1919) differentiated between "solid cradles" and "ribbed cradles". The sling from Lovelock Cave has a netted pouch but Means would probably describe the pouch as "solid". Solid pouches may be made of a patch of leather (Dohrenwend 2002), or may be created by weaving textiles. Ribbed cradles are sometimes made by splitting the braid of the cord (Means 1919: Plate 25 #3, Plate 26 #2) and sometimes through creating separate woven elements (Tosso 2009, Means 1919: Plate 24 #2, Plate 26 #1).

Other design variability is primarily in size. Pouches vary both in length and width, the size and shape of preferred ammunition is a probable cause. The most important design element appears to be cord length. Most sources suggest that cord length presents a trade-off between velocity (and hence distance and power) and accuracy. A throwing motion may be thought of as generating velocity along the circumference of a circle, when the object is released it travels linearly along the tangent to the circle. A sling adds mechanical advantage by increasing the radius of the circle (usually just the arm of the thrower), so the longer the sling the more advantage is added. Creating a wider circle also magnifies any errors in release timing. Also, a practical limit is imposed on sling length by the height of the user and the amount of space needed around the user to throw. The slingers from the Balearic islands famously wore three slings of varying length to battle, presumably to address the issues raised above (Korfmann 1973).

Current Data

For researchers concerned with military sling use, two issues dominate the discussion of slinging: range and impact (Dohrenwend 2002, Finney 2006, Korfmann 1973, Vega and Craig 2009). How far, and to what effect, a slinger can cast projectiles has obvious implications for understanding ancient warfare. Unfortunately, no consensus has been reached by researchers on either topic.

Concerning the range of sling projectiles, there has been wild disagreement among researchers and enthusiasts alike. Those expressing high-end estimates tend to cite historical evidence, ethnographic evidence and personal experience, while low-end estimates are usually the result of controlled experimentation. To cite the historical sources here would be exhaustively tedious and of little real value. Summaries may be found in Echols (1950), Korfmann (1973), Vega and Craig (2009) and Dohrenwend (2002). These data should all be taken with a grain of salt. Likewise, in spite of a healthy amount of love for empiricism, this author has reason to doubt the experimental results, as will be demonstrated.

Finney (2006) excelled in precise measurement, but unfortunately had an inappropriate subject. While his efforts to minimize error in his study are commendable, he was only measuring his own self-admittedly amateur ability. Since we do not know how Finney compares to other contemporary slingers, what we can learn from Finney's study is limited. The effort made to accurately measure throws truly is commendable, as are his diagrams of English hillforts, his discussion of determining impact effects (discussed later) and his extensive historical research. However, I contend that any data generated by untrained slingers is simply likely inaccurate, and it is likely that much of Finney's excellent modeling will need revision as new data becomes available.

Vega and Craig (2009) take a slightly less sophisticated approach to measurement but at least attempted to measure something relevant. While Finney essentially measured his own skill with a sling, these researchers' measurements are based on Peruvian herders—purportedly "experienced slingers" (Vega and Craig 2009: 1264). Methods for recording distance were adequate: relying on GPS points of release and impact. Unlike Finney's study, Vega and Craig did not record time of flight, which is necessary for velocity calculation. I find issue only with the lack of information given about their subjects. Of fourteen people who accepted invitations to sling, only five used their own—implying the other nine did not have one on their person. No verification of user skill was given, and so looking at Vega and Craig's data we do not know who was skilled and who was not. Instead, throughout the study, reference to 'experienced' slingers references age category—only young adults are considered novice. The researchers record that young adults use slings "much less than older generations," and that women currently do more slinging than men (Vega and Craig 2009: 1268) but we are left wondering what this really means. Does an 'experienced user' throw once a week or once a month? Do some people use slings daily, as suggested by the five people who carried their own slings with them? Who are they and what were their average ranges? Despite the stated goal of the study, we are still left wondering what the average ranges of casts by experienced slingers are. There also may be difficulty among habitual sling users in throwing for distance. Much of good slinging relies on muscle memory, so people who are used to throwing stones directly at near targets (low-trajectory fire) may be unable to adjust to throwing for distance without practice. Since Vega and Craig's method does not measure time of flight (allowing for calculation of initial velocity) we cannot know whether improper release angle affected the results.

Furthermore, analysis of the numbers arrived at by these experiments show the results to be questionable based on common-sense physics. Finney calculates a mean initial velocity of 25.38m/s, which only gives a range on level ground of approximately 66 meters assuming perfect release angle (Finney 2006: 69, 102, 110). This velocity comes out to 56.77 mph, which is slower than a decent high school pitcher's fastball. Since we know that a sling gives its user a mechanical advantage, and that Finney's numbers are below those of a skilled thrower without mechanical advantage, they clearly cannot represent the initial velocity of a skilled slinger. Interestingly, Finney's maximum calculated velocity, 36.96m/s (Finney 2006: 69), comes out to 82.68 mph and would give a maximum theoretical distance of about 139 meters. If we accept the premise that skill represents more than the occasional good throw but consistently good throws, Finney's maximum velocity may be a better measure of a skilled slinger's ability than Finney's mean velocity.

The numbers derived by Vega and Craig are scarcely better. Since time of flight was not recorded they had no way to calculate velocity and thus no way to correct for bad release angles. They found that overall average distance was 66 meters—comparable to Finney's results. However, adults averaged 70 meters and males averaged 78 meters (Vega and Craig 2009: 1267), while one slinger managed a throw of 130 meters and consistently threw over 100 meters per cast (Vega and Craig 2009: Table 2). This throw compares with the maximum calculated range using Finney's fastest throw, suggesting that experience in slinging may be largely about velocity consistency and good release timing. Based on these sources, it seems likely to the author that experienced slingers using stone projectiles would routinely throw beyond 100 meters, with velocities averaging between 30 to 35 meters/second.

Range estimates derived from other sources have the problem of imprecise methods. In ethnographic accounts or informal experimentation, ranges are often judged by eye. However, this lack of scientific rigor should not cause these numbers to be discounted offhand. Korfmann's (1973: 37) claim that Turkish teenagers slung beyond 200m in 5 of 11 trials cannot be too inaccurate. To be sure, the projectiles may have rolled and we do not know the time of flight, release angle, projectile weight or sling length but in evaluating maximum range how much does that really matter? A difference of one or even ten meters is of no interest when evaluating range potential, so a larger degree of error is perfectly acceptable. Interestingly, a throw can exceed 200 meters with a release velocity of only around 45m/s (approximately 100mph). While the young Turkish men in Korfmann's ad hoc experiment were judged by him to be inexperienced, we can gain an idea of what top end slingers can do by referencing the recent world records. David Engvall is the current record holder, with a throw of 477 meters using a specialized sling and a dart projectile. Since this is an unconventional projectile, we may be better off referencing the former record holder, Melvin Gaylor, who in 1970 threw a stone projectile 437 meters (slinging.org). Documentation on how the throws were measured was not available, and thus it is not possible to verify that they are accurate, but the results' acceptance by the Guinness Book of World Records does have some weight. Assuming a frictionless projectile and a perfectly angled release (neither of which can strictly be true), Melvin Gaylor's throw departed at a velocity of 65m/s, in all actuality it would have had to leave the pouch quicker than that. Slinging.org also contains data sent in by enthusiasts using varying projectiles, sling styles and lengths, and throwing techniques. While the data is unverifiable and the methods unscientific, the data are interesting reading and give some idea of what people with varying levels of skill can do.

This still leaves the question of what a sling projectile's effect on the human body would be. Some information can be derived directly from ancient sources. Vegetius says the impact could be more deadly than arrows, and that lethal injury could result without penetration of armor. Celcius, an ancient doctor, included instructions for how to remove lead and stone projectiles from the bodies of patients (Korfmann 1973: 40). Calvin Wells records Peruvian "skulls dug up with small, round depressed fractures...They are remarkably uniform in appearance and are at once intelligible in the light of the frequent archaeological discovery of sling stones among the weapons in the burial grounds" (1964: 19). He furthermore states that the injuries are "almost always well healed" (Wells 1964: 49). Without accurate ideas of the velocities of sling projectiles, little more can be done directly. However, some hypothetical work can provide an idea of sling lethality for if and when good velocity data becomes available.

Dohrenwend makes an attempt to do this, though his analysis is entirely incorrect. He states that it takes "70 footpounds to break most bones in the human body, but less than 2 footpounds to pierce the human body" (Dohrenwend 2002: 36). Energy, however, is not an adequate measure for evaluating terminal effects. How 'sharp' the impact is—in physics terms, how rapid the deceleration of the object on impact—matters, and is not taken into account here. Similarly, surface area matters. Energy transferred over a wide area does not have the same effect as energy applied over a small area. I ran Dohrenwend's numbers, and at 25m/s (remember, these are low numbers for a highschool fastball) baseballs would consistently penetrate the skin of hit batters (.142 kg x 25 m/s ^2 / 2 = 44.4 Joules. Only 2.7 are needed to penetrate the human body). Obviously a more comprehensive measure is needed.

Dohrenwend claims that impact momentum is a better measure of terminal effects than impact energy, basing this claim off a source referencing handgun terminal ballistics (Dohrenwend 2002: 36). This leads him to the conclusion that sling projectiles moving at 192 feet per second are more destructive than modern firearms. To use our baseball analogy once more: a pitch at 25 m/s hits with a momentum of 3.55 kg*m/s (.142 x 25), while a .357 magnum round (158 grain bullet at 1150 fps, or .0102 kg at 350.5 m/s, see ammosupply.com) hits with a momentum of 3.58 kg*m/s. These numbers are essentially identical, but not many people would be convinced that this means a moderately quick fastball is as destructive as a handgun projectile. If it seems ridiculous such grievous errors need to be addressed here, let it be a reminder of the early state of research on sling technology at this time.

A more realistic approach is undertaken by Finney (2006: 112), who recognizes that force, not energy, is the proper unit and that the surface area impacted must be taken into account. Furthermore, he gives a very relevant target number for us to test against: .23kg/square millimeter or 340 lbs/square inch—the force needed to penetrate the human skull (Finney 2006: 74-75). To that end, Table 1 was constructed.

Table 1

Ballistics		**Impact**					
Velocity (m/s)	**Range (m)**	**Energy 30g (J)**	**Energy 50g (J)**	**Energy 70g (J)**	**Force 30g (N)**	**Force 50g (N)**	**Force 70g (N)**
20	43.6	6.0	10	14	300	500	700
25	66.6	9.4	15.625	21.875	375	625	875
30	**94.7**	13.5	22.5	31.5	450	750	1050
35	**127.9**	18.4	30.625	42.875	525	875	1225
40	166.2	24.0	40	56	600	1000	1400
45	**209.6**	30.4	50.625	70.875	675	1125	1575
50	258.1	37.5	62.5	87.5	750	1250	1750
55	311.6	45.4	75.625	105.875	825	1375	1925
60	370.3	54.0	90	126	900	1500	2100
65	434.1	63.4	105.625	147.875	975	1625	2275
70	503.0	73.5	122.5	171.5	1050	1750	2450

Velocity and Range: 30-35 m/s suggested by evidence from Vega and Craig (2009) and Finney (2006)
45 m/s is suggested by the informal experiment of Korfmann (1973)

Energy: Yellow highlight – penetration of skin
Red highlight – breaking of 'most bone'
Force: Yellow highlight – partial cranial penetration by stone projectile
Orange lettering – partial cranial penetration by lead projectile
Red lettering – complete cranial penetration by lead projectile

For velocities 20-70 m/s, I give the hypothetical maximum range in meters. This assumes a 45-degree release angle, level ground and a frictionless projectile—real ranges would be reduced according to the aerodynamics of the projectile. I also give the impact energy in Joules for three weights of projectile. In yellow are the projectiles that according to Dohrenwend would break skin, in red are those that would break bone. As we have discussed, however, these data are not very meaningful.

Force is a more relevant statistic. Once again, force is given for three common weights of projectile, but the color scheme of the graph and the mathematics behind it are a little more complex. First of all, force is related to acceleration, not velocity. What we need to know is how fast the projectile comes to a stop when it hits a human head. Unfortunately we do not, but Finney assumes a deceleration time of 1/500 second (2006: 112), so we will use that as well. Recall that surface area matters. Assuming a spherical projectile, we can use the density of the material to arrive first at a volume, then a radius, and finally a cross-sectional area. (The cross-sectional area serves as an unfortunate proxy, since it would be considerably difficult to determine the impacting area of a sphere as both the stone and the skull deform slightly on impact) The density Finney gives for his stone projectiles is 2.49 grams/cc (2006: 102). Using this we can calculate the size of the sphere and then find its cross-sectional area. This area can be multiplied by the value required to penetrate the human skull to generate a critical value for complete penetration. This is marked by red highlight. The cross-sectional area is halved to give an idea of partial penetration, this is marked in yellow highlight. No red highlight is visible on the table precisely because, at the velocities shown, stone projectiles do not concentrate enough force on target to fully penetrate the human skull.

The same calculations were then repeated using lead as the projectile material. Lead's density is 11.34 grams/cc, much denser than Finney's stones. Consequently the cross-sectional area is much reduced and the penetrating effects are much increased. Red letters indicate complete penetration of the skull, while orange denotes partial penetration. This exercise, even using hypothetical projectiles at varying velocities, clearly demonstrates the enhanced lethality of lead projectiles over stone projectiles, and their relevance to the study of ancient warfare.

Looking at velocities in the range predicted by a critical reading of Vega and Craig (2009) and Finney (2006), we see that with stone projectiles enough concentrated force is not generated to partially penetrate the cranium. Values for the heavier projectiles are close, however, and small depressed fracture would likely be a result. This data actually accords well with the analysis of head wounds by Wells (1964), where most depressed fractures were not fatal. Using lead projectiles, however, the skull is fully penetrated by most of the throws. Using velocities derived from Korfmann's (1973) experiment, lethality is greatly increased. Even stone projectiles show partial penetration of skulls for the heavier projectiles, blows more likely to be lethal to the recipient. Lead projectiles, of course, show complete penetration of the cranium across all weight classes at this velocity.

Experimental Sling Construction

Two experimental slings were constructed. Several how-to articles were consulted (Bollinger, Forsyth, Santiago, Tosso 2009) and surviving prehistoric examples were emulated (Heizer 1952, Means 1919), but no attempt was made to reproduce any specific artifact or design.

Both slings were begun as follows. Three 10' lengths of twine were cut and held together at the midpoint. A three part braid was begun in each direction to make the circumference of the finger loop for the retention cord. When judged sufficient, the braid was gripped at the midpoint, allowing the loose strands (now six) to hang downward. Pairs of strands were selected from each side and the same three part braid was used for the main cord, now each part now consisting of two lengths of twine instead of one. Forsyth and Tosso's (2009) respective descriptions of this process are excellent references.

Braiding proceeds until an approximate midpoint is nearly reached. At this point the pouch is created by splitting the braid into two three-part braids. Each new braid is run to the same length to make the desired length of the pouch, the separate braids are then recombined in the same manner as to complete the finger loop. See Forsyth for a description of this process.

The release cord is braided in the same style as the retention cord, with two optional design traits. First, the release cord may be tapered. This is accomplished by selecting a braid part (a pair of twine lengths), cutting one length of twine approximately two inches above the braid and tying it to the continuing pair. The braid is then continued until the knot is subsumed into the braided cord. The process is then repeated for the other two braid parts so that each part of the braid is reduced to one length of twine.

The second option is the creation of a release node. Sometimes this consists of a bead, but most commonly is simply a knot. The sling is held in the firing hand, with the finger loop around the desired finger, I found the middle to be easiest to use but it is a matter of preference. Pressure is applied to the pouch to stretch the cords straight. The release cord is held between the thumb and the second knuckle of the index finger on the throwing hand. Adjust the pouch so that the very middle and widest part of the pouch is the most distal (both "sides" of the pouch should be equal). Mark where the release cord is gripped and knot the cord at exactly that spot. This process makes finding the ideal hold point easy to find during use.

The two slings are not exact copies of one another. The first is shorter, stiffer, and has a leather patch sewn onto the pouch. Its stiffness seems to come from three factors: firstly the braid is not as tight on my first sling as on the second. If a third sling was produced, I expect it would be very similar to the second since care was taken to make that as tight as I could. Secondly, the tapering of the release cord was begun late, so the release cord consists of six strands for most of its length. Finally, I decided to wrap portions of the braid to protect them from abrasion. The finger loop and the cord to either side of the pouch for a length of about two inches were wrapped using jute twine.

The leather pouch was added for a few reasons. Firstly, there is a risk of the projectile slipping out of the pouch unintentionally. A solid pouch seems to reduce this risk. Secondly, Means (1919) divided Peruvian slings into two categories: solid pouch and split pouch. Since I had resolved to make two slings I decided that I would make one from each category.

Length was increased in the second sling primarily because in the first I began the pouch too early, and had wasted twine past the release node. The second time around I marked the center of the strands once the finger loop was completed. Although I still had some waste past the release node, it was greatly reduced by this method.

	Length*	Pouch Style	Pouch length**	Pouch width**	Taper length***	Taper mean***
Sling 1	70.5cm	Solid, leather	12cm	5cm	7cm	8.5cm
Sling 2	78cm	Split, 2 braids	9cm	4cm	18cm	45.5cm

*Length is measured from the release node to the center line of the pouch, while the sling is held under tension

**Pouch length and width as static for the solid pouch, but vary for the split pouch as the relationship between the 2 braids change. A stone was placed in the pouch as if for firing (for the stone to be secure the strands must be separated to "cup" the stone, but too much separation allows the stone to squeeze between the braids when spun) and measured then. When thusly opened there is some size variability to account to projectile size and shape, but not a great amount.

***Taper length refers to the distance from the first taper knot to the last. Taper mean is measured from the release node to the midpoint of the taper length. These measurements combined give an adequate description of the shape of the release cord.

Experimental Use

As discussed, skill is a very important variable in sling performance. This study sought only to document my own learning experiences; I made no attempt at measured experiment. During my first session I was lucky to avoid releasing the stone haphazardly—and dangerously—early. Experimenting with various techniques (Dohrenwend 2002: 34-35), I found I was able to throw horizontally if I released on the first rotation. Throwing in a vertical plane proved something of a challenge. While an underhand release was simple to accomplish and could be done at speed, I was unable to sling overhand. Whether the stone would slip out of the pouch or if my release timing was off is hard to say, all I know is the stones came out embarrassingly badly. I managed not a single clean release with this throwing style. I did not attempt the third style described and illustrated by Dohrenwend. Given my inability to master overhand I felt I would be putting myself and my parked car at risk if I tried anything that complicated. Also, it appears that the style is more suited to longer lengths of sling than I manufactured.

The two slings also presented some interesting variability. The first time out I only had the solid-pouch sling. After that session I decided to make a split-pouch sling to see if that would solve anything. I may have in fact made the pouch too small, because problems of inadvertent release were increased. Even throwing underhand, the technique I had the most success with before, I found I had to slow my motions or risk wild throws. Overhand throwing was equally disastrous as the first session. However, during the second session I did manage a clean overhand release with the solid-pouch sling. With more practice I think this technique would be within my grasp. I did not attempt the horizontal style with the split-pouch, once again to protect my person and my car.

In both of these sessions I used limestone gravels, approximately 3-5 cm in maximum dimension, as ammunition. These are not ideal projectiles, but they are plentiful. The spot chosen was the Salt Dogs parking lot near the Haymarket district. The distance from the parking lot island near where I stood to throw and the parking lot island downrange is just over 110 meters. I found it difficult to track projectiles in flight, but when I was able to see them land they all seemed to fall short of the island. I lost track of a single excellent underhand cast which may have cleared the island. These data, extremely rough though they are, seem to be in keeping with the distance one would expect for a novice user.

Future Experimental Considerations

If real experimental work is to be accomplished it would be necessary to either find a skilled user (or preferably, many skilled users) or to develop a reasonable amount of skill over time. The time required for this would be measured in years, it is very clear that slinging is not to be mastered overnight. However, if we are serious about understanding this weapon's role in ancient warfare this could be a worthy commitment. Methods should also be rigorous and well-documented, replicability is key. Having found skilled slingers (something of a rarity in the modern world) it would be a shame to have their efforts discredited through imprecise methods. Time of flight should always be recorded, as should some testament of the user's skill and how habitually they practice. If the user does not normally throw for distance, the experiment must allow enough pre-trial throws so the user becomes comfortable with the change in release. Ideally, projectiles should be of standardized size and weight, it would be easily possible to mold bullets from lead, clay or even concrete. Since estimations of velocity assume a frictionless projectile however, lead should be used since it will provide the most dense and streamlined bullet. It may also be possible to measure velocity directly, if the equipment is available and can be adequately safe-guarded. While the present state of sling research is on simple matters of range and terminal effect, future efforts may go into the relative benefits and disadvantages of various sling forms, projectile shapes or even throwing techniques. So that results may be used to answer these questions as well, those sorts of variables should also be recorded. The description I provided of sling form should be adequate for these purposes though it could certainly be improved. These factors should lead to more accurate studies in the future and, the author believes, generate experimental velocities greatly increased over previous trials.

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