Optimal Data Analysis
2013, Vol. 2, Release 1 (September 27, 2013), 54-59

2155-0182/11/$3.00

Comparing Knot Strength Using UniODA

Paul R. Yarnold, Ph.D. and Gordon C. Brofft, BS
Optimal Data Analysis, LLC   Marine and Water Consultant

This study assessed comparative strength of three versatile knots widely used in big-game fishing. Experiment One compared *Uni* and *San Diego* knots tied in 30-, 40- and 50-pound-test monofilament line (the modal strengths), finding no statistically significant differences in knot strength. Experiment Two attached 40-pound-test monofilament line to 50- and 65-pound-test solid spectra, and to 60-pound-test hollow spectra line using a *Double Uni* knot, and found the 40-to-65 connection was strongest. High levels of variation in knot strength which were observed raises concern about the durability and consistency of monofilament line.

The oldest known hook for catching off-shore pelagic fish was discovered in East Timor, and is estimated to be 42,000 years old.[1] Today, engineered hooks made with corrosion-resistant metals and lines made of plastic (monofilament) and Kevlar (spectra) have made it easier to hook and catch a fish.[2] And today, as yesterday, knots are used to connect hooks and lines, and must be sufficiently durable to survive from hook-up to landing for a catch to be accomplished. Knot strength is studied experimentally and evaluated using statistical methods in academic surgery.[3] but similar evaluation of fishing knots hasn't yet been reported—the purpose of this research.

General Experimental Methodology

A Shimano spring scale accurate to ½ pound used to calibrate reel drags was used to assess pounds of force required to induce knot failure (a sliding pointer indicates the maximum force). The free end of monofilament line was tied directly to the scale, the other end was the top shot on a Penn 113HN fishing reel with the drag cinched closed, mounted on a reel seat and secured in a rod holder. On each trial, once the engineer (GCB) determined the test knot was perfectly tied, he pulled the scale until the knot broke, recorded force at knot failure, and reset the scale pointer. Pulls were steady, and made at a 90-degree angle of attack. Knot testing order was determined via coin flip.

Uni and *San Diego* knots were both tied using seven turns, and the *Double Uni* knot was tied using six turns for monofilament and eight turns for spectra.[2] When tying knots loops were tight with no overlap, cinching was steady with no frictional heating, and tag ends were cut at ¼-inch. Fishing line used in this investigation was 30-50-pound-test P-Line monofilament; 50- and 65-pound-test Izorline solid spectra; and 60-pound-test Jerry Brown hollow spectra.

2155-0182/11/$3.00

Experiment One

This study compared the strength of *Uni* versus *San Diego* knots tied in 30-, 40- and 50-pound-test monofilament line. Ten of both types of knot were tied in three classes of pound-test line, for a total of 60 knots. Knot strength was compared between the two types of knots for each of the three line classes using the following UniODA software[4] code (control commands are indicated in red):

```
open study1.dat;
output study1.out;
vars linetest typeknot pounds;
class typeknot;
attr pounds;
mcarlo iter 25000;
loo;
include linetest=30;
go;
include linetest=40;
go;
include linetest=50;
go;
```

Table 1 summarizes the results of analyses for each of three different line pound-test categories.

Table 1: Findings of Experiment One

	30-Pound-Test			40-Pound-Test			50-Pound-Test	
	Uni	San Diego		Uni	San Diego		Uni	San Diego
N	10	10		10	10		10	10
Median	24.5	27		33.5	34.5		41.5	41
Mean	26.3	27.6		33.2	36.0		39.7	41.0
SEM	1.75	1.38		1.28	1.54		2.58	0.82
95% CI, Mean	23 - 30	25 – 30		31 – 36	33 – 39		35 – 45	39 - 43
SD	5.54	4.35		4.05	4.88		8.17	2.58
95% CI, Knot	15 – 37	19 – 36		25 – 41	26 – 46		23 – 56	36 - 46
Minimum	21	22		27	30		28	37
Maximum	38	38		39	44		49	45

.

UniODA Model	If breaks ≤ 23.5 pounds, then predict Uni knot		If breaks ≤ 29.5 pounds, then predict Uni knot		If breaks ≤ 33.5 pounds, then predict Uni knot
p < for UniODA	0.36		0.77		0.71
ESS	40.0		30.0		30.0

The first row in the top section of Table 1 (N) gives the number of knots tied.

The second row (Median) is the median number of pounds of force required to induce a knot failure. If observed breaking strengths for a given knot/line combination are sorted from lowest to highest, then the median value is the number in the middle (mid-point) of the sorted list. Median values differ only slightly (1%-3%) for knots made using 40-50-pound-test line, and modestly (10%) for knots made using 30-pound-test line. More notable is the consistent failure of either purported “100% knot” to achieve line class: median values are 82%-90% of line rating for 30-pound-test; 84%-86% for 40-pound-test; and 82%-83% for 50-pound-test line.

2155-0182/11/$3.00

The third row (Mean) provides the mean pounds of force required to induce knot failure. Consistent with the findings for medians, mean knot strength differed modestly (3% to 8%; the San Diego knot was consistently stronger), and means were notably lower than was the rated line strength (the deficit increased as line test-class increased): 88%-92% of rating for 30-pound-test; 83%-90% for 40-pound-test; and 79%-82% for 50-pound-test line.

The standard error of the mean (SEM) in row four is an estimate of the standard deviation of observed mean knot strength, and it is used to estimate the range within which the *mean knot strength can vary*, if this experiment is repeated. The expected mean variability is given in row five (95% CI, Mean): a 95% confidence interval for the mean is the range within which the mean knot strength is expected to fall on 95% of the times that this experiment is repeated. Only for 30-pound-test line does the upper-bound of the expected range include line-class rating: upper-bounds were 90%-98% of rating for 40-pound-test line, and 86%-90% for 50-pound-test line. The lower bounds of the expected range were 77%-83% of the rating for 30-pound-test line, 78%-82% for 40-pound-test line, and 70%-78% for 50-pound-test line.

Row six (SD) is the standard deviation, a measure of degree of difference between mean and individual measurements of knot strength, used to estimate the range within which the *strength of individual knots can vary*, if this experiment is repeated. Expected variability of individual knots is provided in the seventh row (95% CI, Knot) as the range within which the strength of 95% of the individual knots is expected to fall if this experiment is repeated. Results parallel findings for means, but are more extreme. Upper bounds of the 95% confidence interval exceeded line-class rating of 30-pound-test line by 20%-23%, and 40-pound-test line by 1%-15%. The upper bound for Uni knots tied in 50-pound-test line exceeded line-class rating by 12%, but it was 92% of line-class rating for San Diego knots. Lower bounds were 50%-63% of line-class rating for 30-pound-test line, 62%-65% for 40-pound-test line, and 46%-72% for 50-pound-test line.

The eighth (Minimum) and ninth (Maximum) rows provide the strongest and weakest observed knot strengths, respectively. Values in these rows all were within the 95% confidence interval for knots in 40- and 50-pound-test line, but the strongest Uni and San Diego knots (38 pounds) tied in 30-pound-test line exceeded the upper 95% bound.

The first row in the bottom section of Table 1 gives the UniODA model. The Uni knot is predicted to be weakest for all three line-class categories, and to break at levels significantly lower than rated line-class strength: model cut-points are 78% (30-pound line), 74% (40-pound line), and 67% (50-pound line) of the rated line-class strength. As seen in row two, differences between knots were not statistically significant. Increasing the number of knots tied eventually would yield statistical significance, because the observed inter-knot differences were predicted with moderate success. On the ESS accuracy index, 0 represents the predictive accuracy that is expected by chance (i.e., the effect of chance is "factored out" so that different models can be compared using a universal index), and 100 is perfect prediction: models with $25 \leq ESS < 50$ are considered to be of moderate strength.[4]

Discussion

It is not surprising to learn the strength of Uni and San Diego knots differs *moderately*. These knots are similar in configuration and the way they cinch down when tightened, and both are rated 100% knots, meaning they will break at the breaking strength of the line—and thus won't diminish the integrity of the rigging. Tied and fished by experts, both knots are extremely reliable. There are typically too few trials (and likely few anglers attempt) to detect the modest difference on a single fishing trip. However, the experimental comparison showed that the San

2155-0182/11/$3.00

Diego knot has moderately greater strength, so a sufficiently large sample of knots will reveal a statistically significant difference. Considered at the individual level, selecting the Uni knot may increase the number of large fish lost over the course of a lifetime for casual anglers, perhaps over the course of a season for active anglers. But for people who hunt for large, fast, powerful fish, if for food, competition, commerce, or record, it is illogical to lose advantage without cause—thus the San Diego is knot of choice.

In contrast, it was surprising to observe how substantially lower than rated line-class the strength of both types of knots routinely fell in Experiment One. Rated line-class fundamentally influences angler decision-making on reel, drag setting, rod, hook and bait selection—and thus on the targetable species. For example, hooking a tuna fish on gear appropriate for much smaller and weaker species is a low-probability catch.

Replication/extension of this research is warranted that compares different monofilament brands, and collects data on a larger number of knots tied by multiple technical experts, so as to assess generalizability across brand and person. It also is important to measure or estimate actual targeted species fighting behavior: for example, head shakes and sudden acceleration both create force spikes. This may be done via simulation or *in vivo*, for example by attaching a hand line to a spring scale. Such mission-critical information regarding anticipated operational force levels is necessary to ensure that appropriate equipment and rigging is selected.

Experiment Two

Experiment Two compared the strength of the Double Uni knot used to attach 40-pound-test monofilament line to: a) 50-pound-test solid spectra; b) 60-pound-test hollow spectra; and c) 65-pound-test solid spectra (the most popular selections for reel backing). Knot failures were examined and the type of failure was recorded. Table 2 summarizes the observed data.

Table 2: Findings of Experiment Two

	60 Hollow	50 Solid	65 Solid
N	14	20	13
Median	23	23	25
Mean	23.4	22.5	25.6
SEM	1.10	0.53	0.90
95% CI, Mean	21 – 26	21 – 24	24 - 27
SD	4.13	2.35	3.25
95% CI, Knot	15 – 31	18 – 27	19 - 32
Minimum	18	18	21
Maximum	30	27	32

.

As in Table 1, the first row in Table 2 (N) gives the number of each type of knot tied. During trials the free end of the monofilament line was tied to the spring scale via a San Diego knot. This knot broke twice (32 and 26 pounds) testing the 40-60 combination, and once testing the 40-65 combination (30 pounds). These trials broke experimental protocol and thus were not included in the study. However, it is interesting to note the UniODA model identified earlier for 40-pound-test monofilament (Table 1) used a cut-point of greater than 29.5 pounds to predict

2155-0182/11/$3.00

a San Diego (versus Uni) knot. For two of the three misfired trials (those with knots breaking at 30 and 32 pounds) the San Diego knot was correctly identified by this model.

The second row (Median) is the median pounds of force required to induce knot failure. Because the weakest rated strength of a rigging component in Experiment Two is 40 pounds, it seemed plausible that strength comparable to results in Experiment One for 40-pound-test line might be observed. Surprisingly, median values are 33% lower than medians reported for 40-pound monofilament in Experiment One, and instead are comparable to reports for 30-pound-test line. The mean (row three) and median (row two) values are highly consistent.

Variability (SEM, SD) in knot strength scores is significantly reduced in Experiment Two versus Experiment One, resulting in much tighter (smaller range) 95% confidence intervals for means and knots. Parameters for 65-pound-test spectra consistently exceed those for the 60- and 50-pound spectra, but overall findings are most consistent with results for 30-pound-test monofilament line from Experiment One.

Knot strength was compared between the three types of spectra using the following UniODA code (control commands are indicated in red; non-directional exploratory analysis is conducted as no *a priori* hypothesis was made):

```
open study2.dat;
output study2.out;
vars spectra pounds;
class spectra;
attr pounds;
mcarlo iter 50000;
loo;
go;
```

The resulting UniODA model was: if pounds≤20.5 then predict spectra=60; otherwise if pounds<20.5≤24.5 then predict spectra=50; otherwise if pounds>24.5 then predict spectra= 65. The model achieved a moderate ESS of 36.0 ($p<0.03$), which fell but remained statistically significant in jackknife validity analysis (ESS= 18.2, $p<0.02$). The model correctly classified 6 of 14 (43%) 60-pound-test spectra knots; 12 of 20 (60%) 50-pound spectra knots; and 9 of 13 (69%) of 65-pound spectra knots.

The three pairwise comparisons between types of spectra were performed by adding the following code to the end of the program (dir specifies the *a priori* hypothesis that the order of effect identified in the omnibus UniODA model will be retained in the pairwise comparisons):

```
exclude spectra=50;
dir < 60 65;
go;
exclude spectra=60;
dir < 50 65;
go;
exclude spectra=65;
dir < 60 55;
go;
```

Comparison of 50- and 65-pound spectra achieved strong jackknife-stable ESS of 54.2 ($p<0.005$). The UniODA model was: if pounds ≤24.5 then predict 50-pound spectra; otherwise predict 65-pound spectra. The model correctly classified 17 of 20 (85%) 50-pound knots, and 9 of 13 (69%) 65-pound knots.

Comparison of 50- and 65-pound spectra achieved moderate ESS of 42.9 ($p<0.04$), which fell in jackknife analysis (ESS=35.2, $p<0.05$). The UniODA model was: if pounds≤20.5 then predict 60-pound spectra; otherwise predict 65-pound spectra. The model correctly classified 6 of 14 (43%) 60-pound knots, and all 13 (100%) 65-pound knots.

Finally, comparison of 50- and 60-pound spectra yielded weak ESS of 17.9, which wasn't statistically significant ($p<0.41$).

Failure Analysis. Following each trial the engineer examined rigging to determine the nature of the failure.

2155-0182/11/$3.00

For 50-pound-test solid spectra, for 20 trials, every failure involved monofilament line cutting spectra line.

For 60-pound-test hollow spectra, for 14 trials: Double Uni pulled-out three times (21%); spectra cut monofilament eight times (57%); monofilament cut spectra three times (21%).

For 65-pound-test solid spectra, over 13 trials: Double Uni pulled-out three times (23%); spectra cut monofilament four times (31%); and monofilament cut spectra six times (46%).

Discussion

The primary finding in Experiment Two is significantly lower rigging strength relative to rated line-classes of rigging components. It is not surprising that Double Uni knot strength in the tested capacity was lower than the strength observed for either knot studied in Experiment One: as complexity increases, opportunities for failure increase concomitantly. The *zeitgeist* in tuna fishing is turning away from tying knots or crimping lines together, and toward the use of splicing, either directly to the reel, or off the reel using wind-on leaders.[2] Presumably, reduced complexity will produce stronger, more reliable rigging connections: this *a priori* hypothesis should be verified experimentally.

A few recommendations are suggested by the present research. Knots are very difficult to tie well using hollow spectra line, so this should be avoided. And, use 30-pound-test (or weaker) monofilament with 50-pound-test solid spectra line, and 40-pound-test monofilament with 65-pound-test spectra line.

References

[1]O'Connor S, Ono R, Clarkson C (2011). Pelagic fishing at 42,000 years before the present and the maritime skills of modern humans. Science, 334:1117-1121.

[2]Philpott L (2008). *The complete handbook of fishing knots, leaders, and lines*. Skyhouse Publishing**.**

[3]Chi T, Eisner BH, Berger AD, Stoller ML (2010). An ex-vivo evaluation of the application and strength of a novel laparoscopic knot substitute device. Endourology, 24: 95-98.

[4]Yarnold PR, Soltysik RC (2005). *Optimal Data Analysis: A Guidebook with Software for Windows*, APA Books.

Author Notes

Appreciation is extended to "Rock Cod" Rick Maxa for his review and helpful comments on this paper. Correspondence by mail should be sent to: Optimal Data Analysis LLC, 1220 Rosecrans St., #330, San Diego, CA 92106.