Tom Evans and Sarah Truebe Bios:

Tom attended the University of Washington and earned four bachelor's degrees (Geology, Biochemistry, Cell Biology, and Evolutionary Biology), then attended Washington University and earned an M.A. in Geology.

Sarah is currently working at Stanford University as the Director of Community-Engaged Learning in Environmental Sustainability, which has little to do with her interests in technical rescue!

Abstract - 2- 30 minute presentations: A Review of Knot Strength Testing, and A Review of Friction Hitch Testing

The variables investigated for Knot Strength include: absolute knot strength, software strength reduction, strength comparison between knots, effect of material (nylon, polyester, etc.), construction type (rope, cord, or webbing), diameter, testing speed, aging, wet or dry, and how many tests have been performed on a variety of knots.
Friction Hitch Testing: Presented here is a literature review of existing friction hitch testing, including both slow pull and drop testing on a variety of friction hitches tied with cord, webbing, and rope, covering 116 citations.

A Review of Knot Strength Testing

Thomas Evans, SAR[3], http://sarrr.weebly.com/

Introduction

Nearly all rope systems use a knot or knots in their construction, so understanding the strength and behavior of knots in a variety of materials is important for understanding system tolerances. This also means that the strength of knots is a heated topic, one that can cause stern conversations between professional and volunteer riggers alike. However, when pressed to provide data, rarely can riggers trace their strong opinions to publically available testing data. As a result, there is quite a bit of rigging lore associated with knots, knot tying, and knot usage that may or may not be consistent with reality.

To gain a grasp of the state of rigging knot science, a literature review was performed. This paper is a data mining exercise designed to determine what we know and do not know about rigging knots. This article does not publish any new data, but instead produces analyses of existing data published by others. The synopsis of the meta-analyses provides some interesting results and shows what questions need to be addressed with further research.

Methods

A literature review was accomplished by searching through the readily available published literature (books, magazines, ITRS proceedings, etc.), followed by extensive Google and Youtube searches. A study was included only if (1) the knot(s) tested could be identified, (2) there was a way to identify the methods used to gather the data, (3) some form of data was presented (individual results, synopsis statistics, both, or either), (4) if knots were tied with a single strand of software (no multipoint anchors). Articles on knots in materials other than rope, cord, or webbing were excluded as well, for example, articles on knots in proteins, metal cables, or fishing line. Data and metadata for each citation was entered into a spreadsheet for direct comparison. The spreadsheet includes: knot type, if a control was performed (and how many), if new or used software was tested, pull rate, if a drop test was performed, the average, standard deviation, maximum, minimum, range, failure location, if the software was static or dynamic, makes and/or model of rope webbing or cord, diameter or size, composition, and the citation. Most of the studies had missing or omitted information, so when information was unknown it was recorded as unknown, and if the column was unnecessary a (-) was included to make it clear to the reader why information is missing in the combined spreadsheet.

Every attempt was made to be thorough, however, undoubtedly studies were missed. This data set should be used as a minimum representation of the available data. If you are aware of other studies, or you have data sets you are interested in adding to this combined analysis, please contact SAR[3], and we will publish your data and add it to the combined suite of information.

Data were mined to determine the effects of software age, hydration (wet vs. dry), speed of test, software diameter, and construction. Additional information was collected on the variation in knot strengths, and the absolute strength loss of knots when controls are available. The number of samples tested, and the knots tested were collated to estimate what knots have been tested the most and how. Lastly, because the relative strength of bowlines and figure 8s on a bight was a frequent theme of testing, the results from these two knots are compared to provide a useful synopsis for users. Generally the results of studies with the relevant information for a given analysis were combined into a spreadsheet and plotted on the same graph for ease of comparison.

It is acknowledged that the studies presented here use different methods, different materials, etc., and that their results cannot be compared directly without incurring error. By plotting the results from many studies side by side it is hoped that larger scale patterns will emerge that deemphasize the variability in results due to methods alone. Readers should take the results with a grain of salt and understand that the results are general at best, and should be supported with further targeted hypothesis driven empiricism or experimentation.

Results

A total of 114 sources were used, with a total of >1440 tests for the combined analysis. The knots most tested are those used most frequently in rigging (Figure 1), with the figure 8 on a bight, double fisherman's bend, bowline, overhand bend, and flat overhand bend being the five most common knots tested. Table 1 lists the 16 knots with at least 21 test results available across all sources, and Figure 1 shows the relative number of tests for each knot described in Table 1.

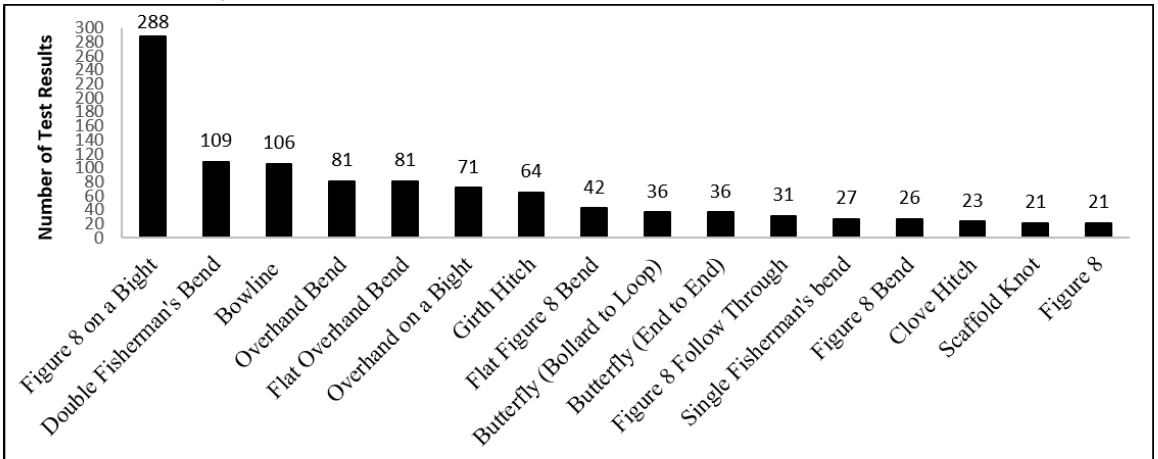

Figure 1: Number of test results for the sixteen most commonly tested knots, all with 21 or more data points reported.[1]

Studies report sample sizes between 1 and 12 (Figure 2, Table 2) with the vast majority of measurements reporting sample sizes of 1 (N=636), with 6 or less being the most common sample numbers when multiple samples were tested.

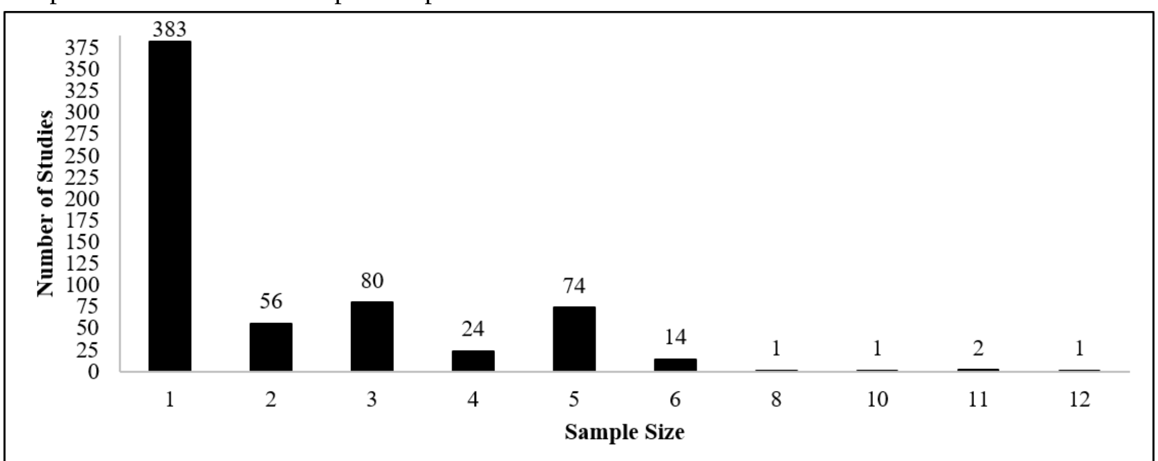

Figure 2: The number of knot tests reporting a given sample size.[1]

Residual knot strength, calculated as a percentage of the average control strength of unknotted software, is plotted in Figure 3 (N=132) for every knot comparison possible from the combined data set. There is a distinct band of data between ~45% to ~85% (Figure 3) of the unknotted software strength in which the vast majority of measured knot strengths fall between. For a given knot there is a range of residual strengths (Figure 4), a range which overlaps the ranges of other knots. This same information is presented in table form with ranges of residual knot strengths (Table 3), because this is the format the rigging community is accustomed to seeing this information presented in. When comparing the same knot in webbing, rope, and cord (Table 3), the knots have approximately the same strength. These data should be interpreted conservatively because of small sample size artifacts (Table 3).

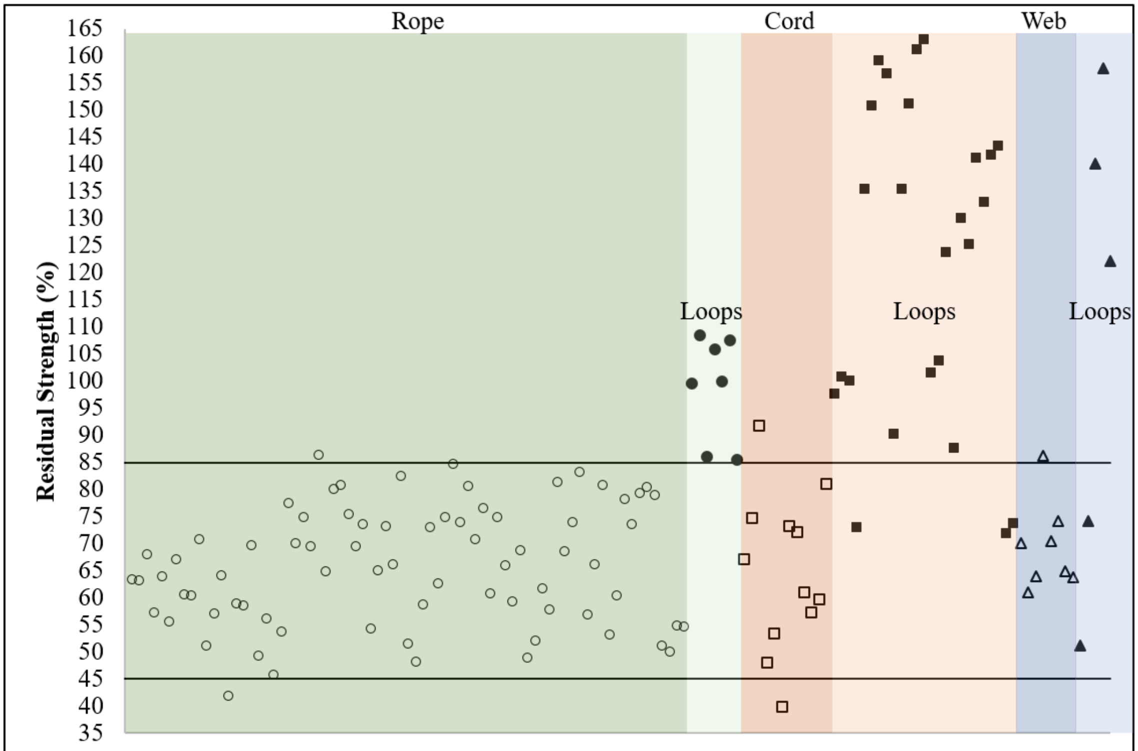

Figure 3: Residual knot strengths for all possible comparisons. Green are knots in rope, orange are knots in cord, and purple are knots in webbing. Knot tests using a loop of software are solid shapes. Most values reside between 45% and 85% residual strength.[1]

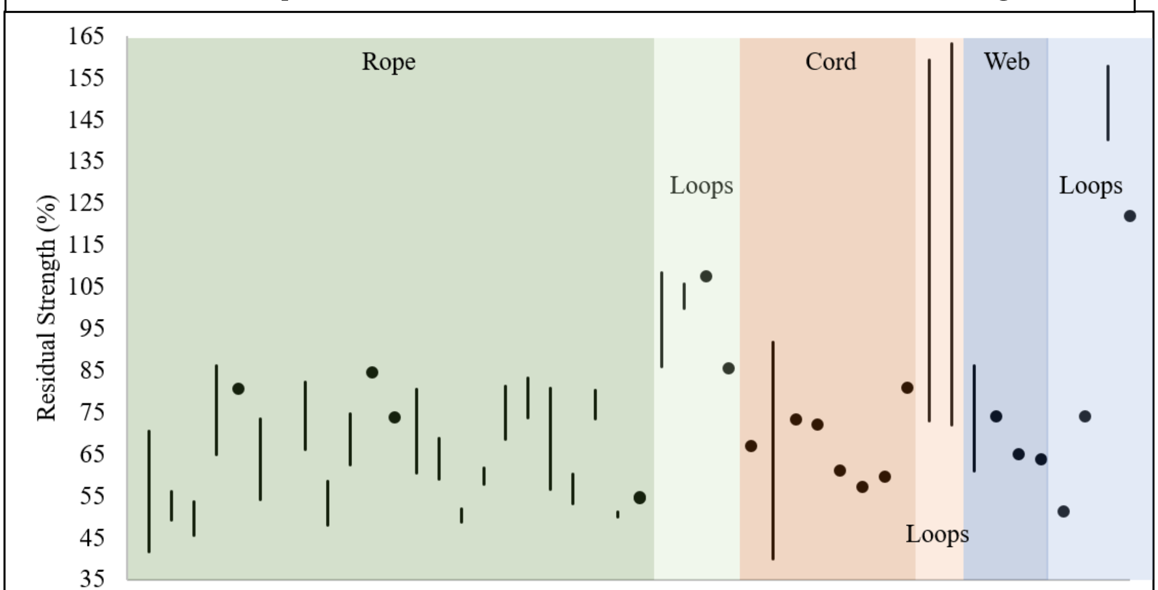

Figure 4: Range of knot residual strengths compared directly. Each line is the range of knot strengths reported, each circle is an individual test. See Table 3 for the number of studies that informed the ranges depicted here. There is considerable overlap in strengths between knots.[1]

To determine how variable knot strengths are in a population the standard deviations in knots strength data sets were plotted for those studies with 6 or more measurements of knot strength (N=19, Figure 5). Data from small sample sizes were not included because standard deviations are more representative of a population when a larger sample size is used. Sample sizes of between 6 and 12 are still small, thus these estimates are probably underestimates of the full range of variability. However, regardless of software type (rope, webbing, or cord), the standard deviations were low: almost always less than 2 kN. Other variables may also affect residual knot strength and are discussed below.

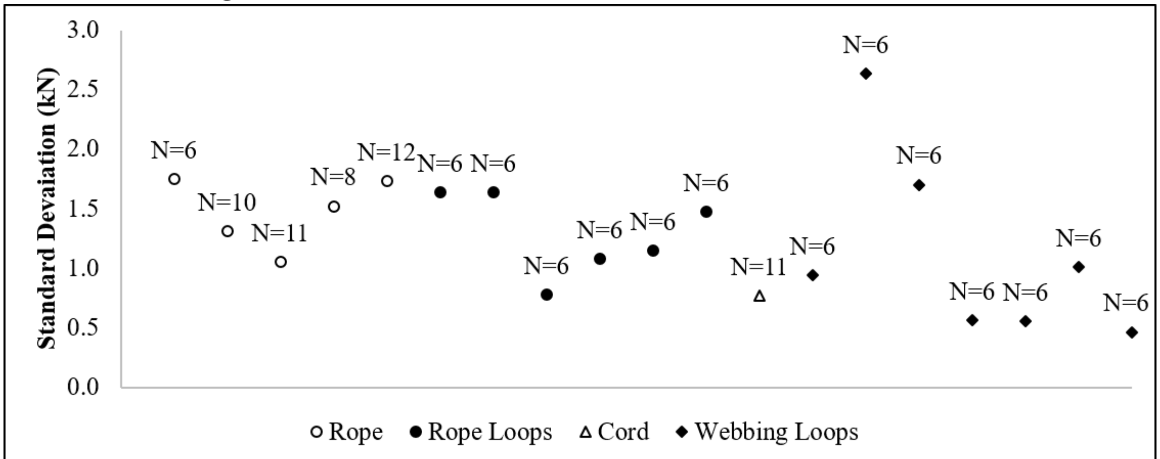

Figure 5: Variability in knot breaking strength between studies with six or more samples.[2]

Rope Diameter. Comparing the knot strengths in rope (Figure 6a) and cord (Figure 6b) of different diameters, the knot strengths are, unsurprisingly, stronger in larger diameter materials. However, when plotting the data from Detter et al. (2008) and Vines and Hudson (2004), there is a trend for knots in larger diameter materials to retain less of the original unknotted strength (Figure 7). It is unclear if this trend is a function of their data analysis technique, or it is a real phenomenon. A controlled study is needed to investigate this relationship. Webbing also shows increased knotted strength in wider materials (Figure 6c).

Testing/Pull Rate. With only four comparisons available, there appears to be a reduction in knot strength with increasing testing speed (Figure 8). This means part of the variability in knot strengths observed is due to testing procedures. Unfortunately, with such a small sample size it is impossible to quantify the relationship between test speed and breaking strength. It is likely the relationship is also controlled by composition (e.g., nylon, polyester, Dyneema, etc.), and construction (rope, cord, or webbing).

Wet vs. Dry. The effect of wetting software on knot strength is unclear. Plotting both the wet and dry strengths of software (Figure 9a, N=37) shows no consistent pattern, with some wet samples being both stronger and others weaker than the dry samples. To clarify the relationship, the wet strength was recalculated as a percentage of dry strength and plotted in rank order (from smallest to largest); no pattern emerges (Figure 9b).

Age. Knot strengths in used and/or older software is lower (N=7, Draughon 2004, Drummond 1968, Powick Unknown Date D, Unknown Author Unknown Date). Ideally it would be possible to regress the strength of knotted materials over time, however insufficient data are presently available to perform that analysis. The most that can be reasonably surmised from the data presently available is that older or used materials have lower knot strengths.

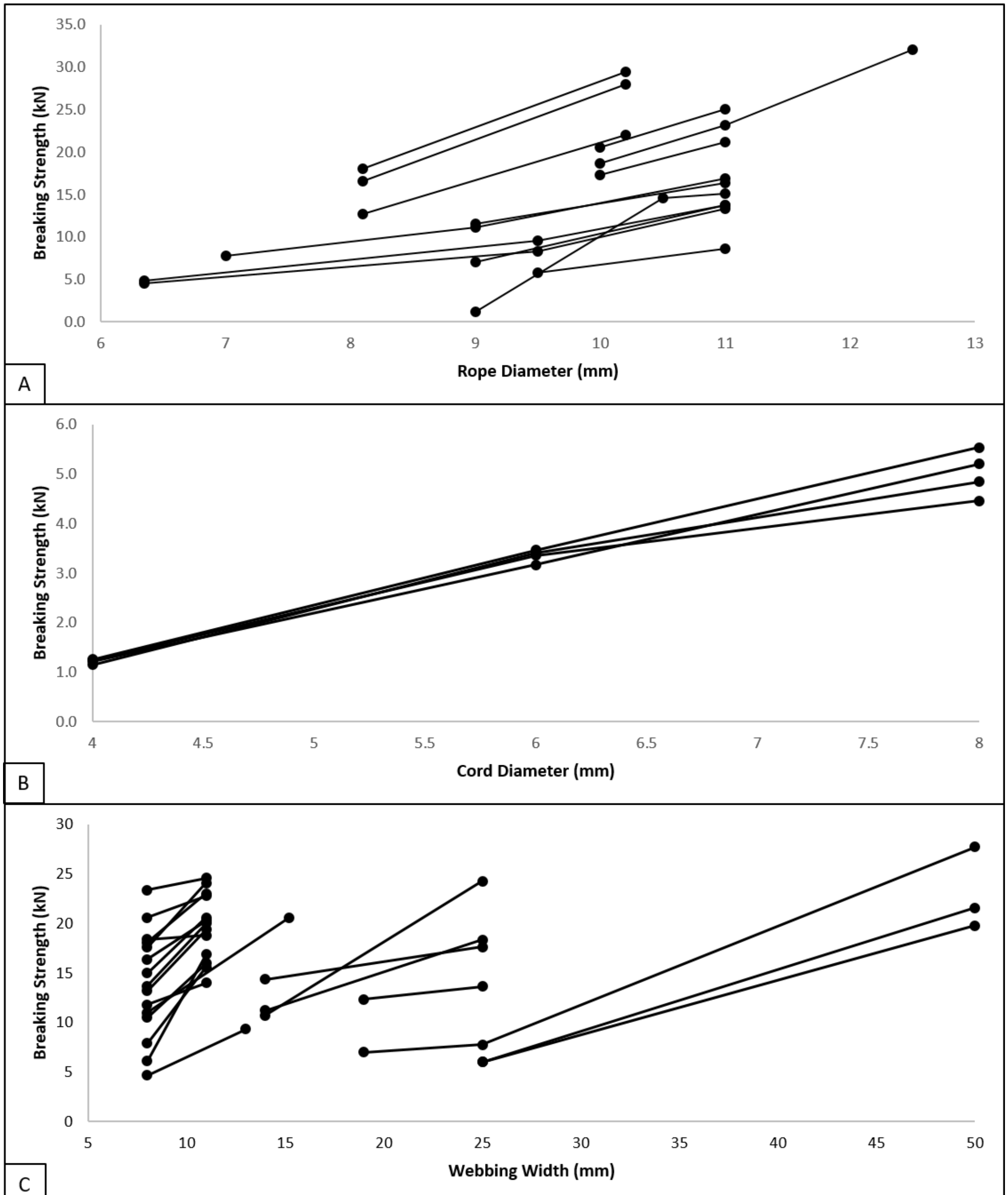

Figure 6: Knot breaking strengths in rope (**A**), cord (**B**), and webbing (**C**) of various sizes. Lines connect data for the same products in different diameters or widths.[3]

Composition. The effects of product composition are difficult to identify because there are few studies that compare the strengths of software of different compositions and sizes. However, there is enough data to roughly compare nylon and polyester products. Nylon appears to be stronger than polyester, though by how much it is unclear (Figure 10). Data in Figure 10 is compared by drawing lines between nylon and polyester products of the same diameter, and most lines slope down to the right, indicating polyester products are generally weaker for a given diameter.

A comparison of bowline versus figure 8 on a bight knot tests shows that figure 8 on a bight knots are stronger than bowlines in nearly all the studies reviewed (N=13, Figure 11a). Similarly, the residual strengths of the figure 8 on a bight knot are higher than the bowlines, however the ranges of residual strengths overlap considerably (41.8-70.7% for bowlines, and 64.8-86.3% for figure 8s on a bight, Figure 11b). This means that there is no one residual strength for a bowline or a figure 8 on a bight; there is a range (just like other knots), and those ranges overlap, suggesting that some bowlines are stronger than some figure 8s on a bight, as supported in head to head testing of these two knots (Bavaresco Unknown Date, Evans 2012, Moyer 2000, NZcaver 2010, 2012, Richard Delaney 2012e,d). In other words, bowlines are usually weaker than figure 8 on a bight knots, but sometimes the figure 8 on a bight is weaker than a bowline in the same material and under the same conditions.

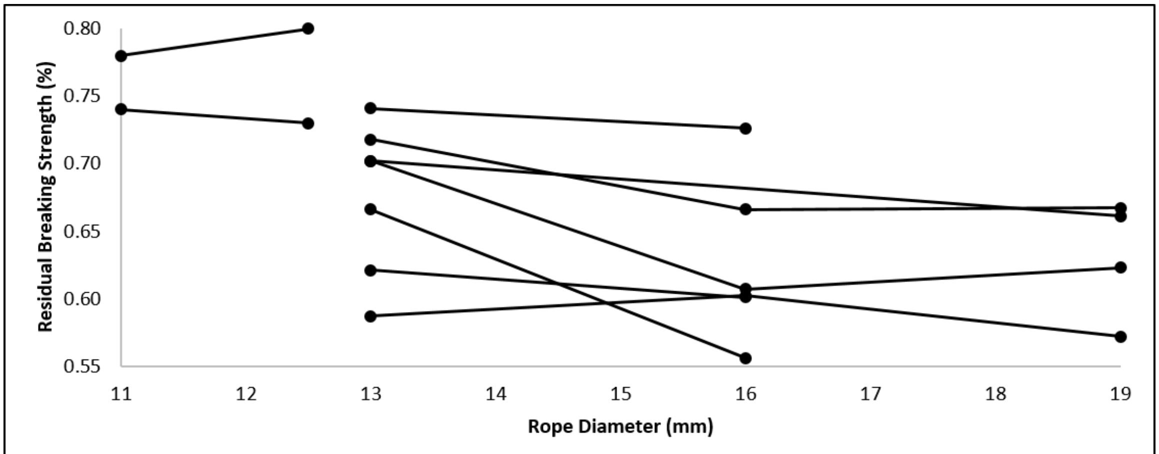

Figure 7: Knot residual strength as a function of software diameter. It appears residual strength decreases with increased size.[4]

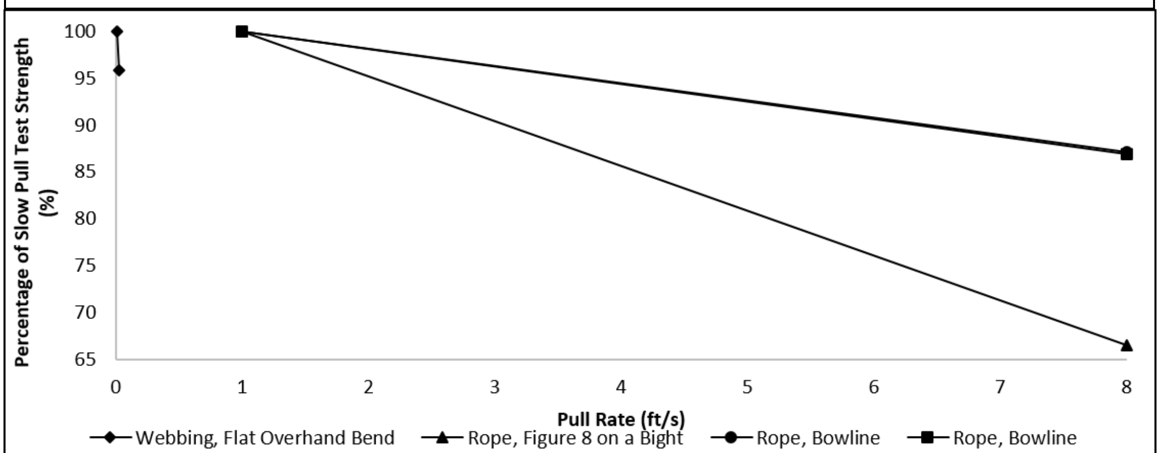

Figure 8: Knot strength as a function of test rate. Faster pull rates yield lower strengths.[5]

Conclusions

The knots tested are those that are used most frequently in sport, rescue and professional rigging, so people are probably testing what they use. This leads to a data asymmetry problem, where it is unclear if rarer knots are stronger or weaker than common knots, or if we just have considerably fewer data for them. What is clear is that all knots in this analysis are strong enough. Testing data appears to be used simply to justify present rigging practices rather than used to pick which practice is "best" based on the values of the rigger (e.g., strength, speed, etc.).

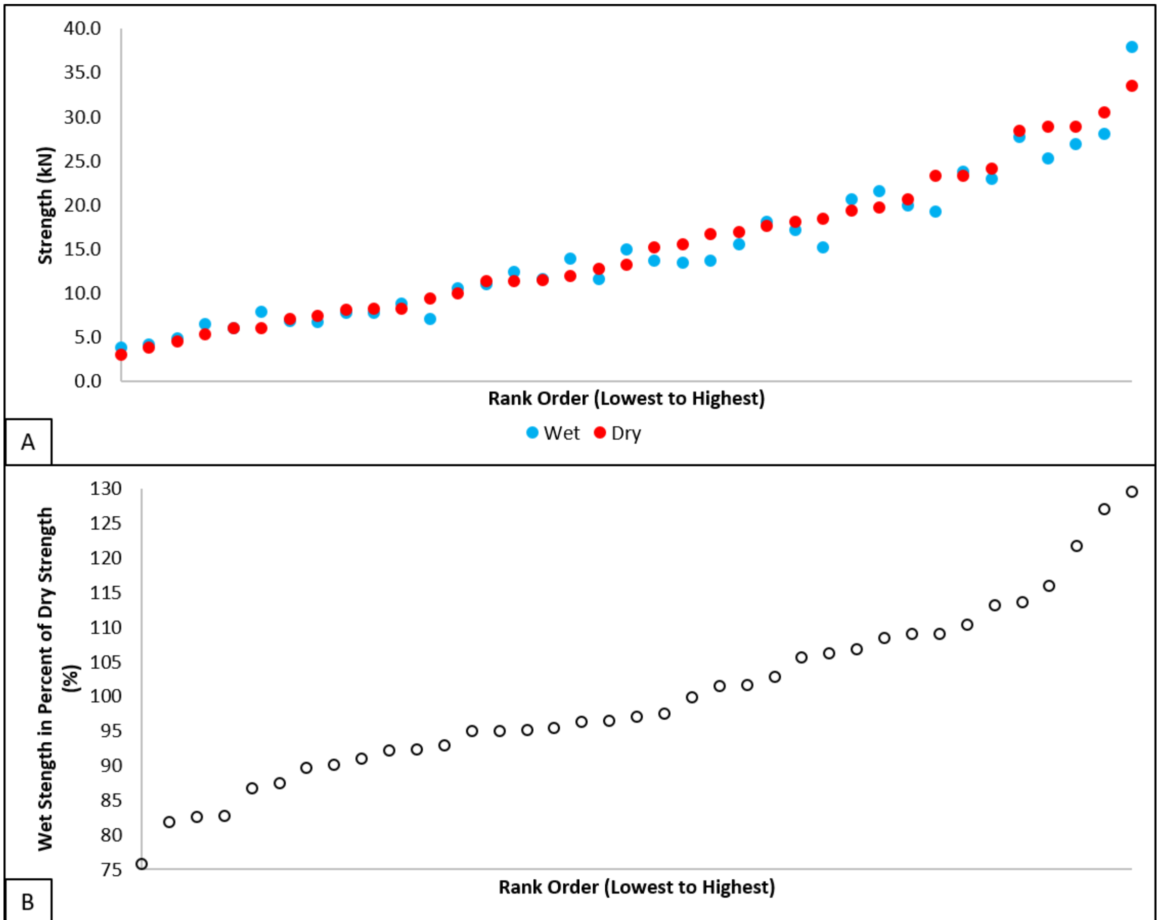

Figure 9: The effects of wetting software on knot strength. **A**) Dry samples in red, and wet samples in blue, **B**) Lowest to highest wet strength as a percentage of dry strength.[6]

A meta-analysis of testing data shows how powerful small "backyard" studies are when combined. Keep doing backyard testing, but document the study and publish the data! SAR[3] or ITRS would be happy to archive these results. The low number of replicates in most studies probably reflects convenience sampling (sample sizes of one or two), which likely stems from the need to get a "good enough" answer with 1-2 samples. This results in many studies that are inadequate to constrain the variability in knot behavior. Please also consider performing studies of knot strength with large sample sizes to constrain variability when it is feasible financially or time-wise.

Few studies incorporated a control or controls in their design, which reduces our understanding of the average percentage strength *loss* in knotted rope relative to unknotted. What is clear from the controlled data we have is that there is no consistent percentage strength loss for a given knot; there is a range. The ranges of strength loss between knots overlaps, therefore determining the "strongest" knot is not straightforward. It is better to conceptualize knot strengths as range comparisons, with one knot, on average, stronger or weaker, and with different ranges of variability. Moreover, strength reductions are partially a function of material type (e.g., nylon, polyester), so until we have more controlled data, the numbers provided are only useful estimates.

The range of variability in knot breaking strengths was generally narrow (under 2 kN), which is similar to other studies on software variability (Evans 2013, 2014, 2015a,b,c, 2016, Evans and Stavens 2011, Evans and Truebe 2015, Evans et al. 2012). This consistency is probably a function of consistent manufacturing quality of the products tested.

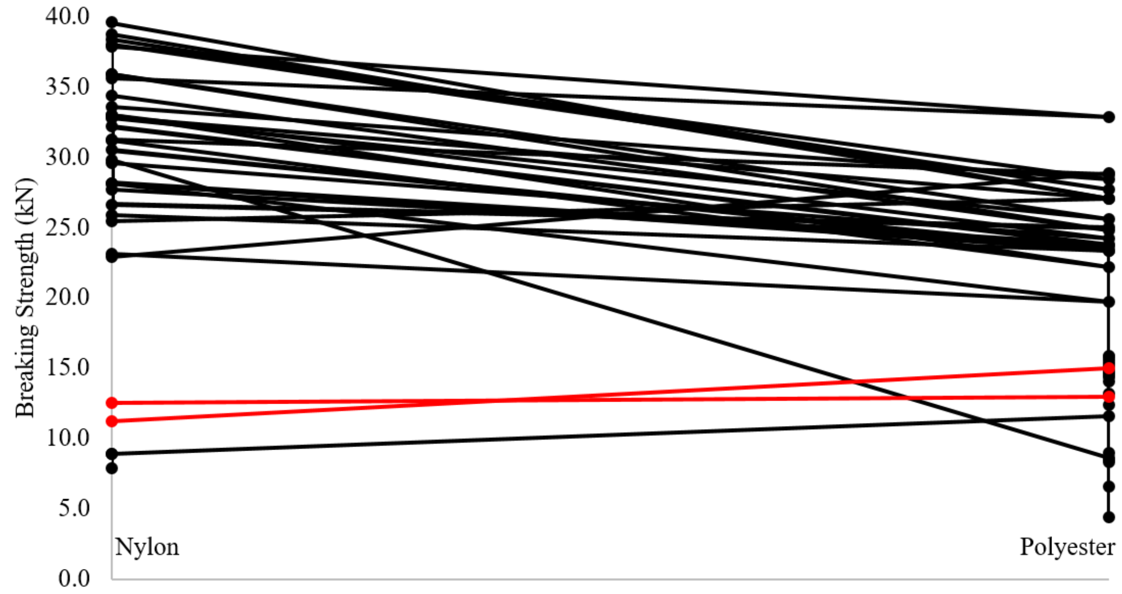

Figure 10: Relative knot strengths tied in Nylon versus Polyester software of the same size. Nylon breaking strengths are on the left, polyester on the right. Most lines move down and to the right indicating polyester is weaker when knotted. Black lines are results from rope, red lines are results from webbing.[7]

As expected, larger diameter or width materials had higher breaking strengths. Thus getting a bigger rope, thicker cord, or wider webbing makes the system stronger. However, the relative strength reduction in the knots may be higher in larger materials. This relationship between diameter (or width for webbing) and residual strength, needs to be investigated empirically and systematically.

The rate at which a pull test was administered also altered the results, which indicates that part of the variability in published knot strengths is due to testing method. Because knots are loaded at a variety of rates in practice, all of these tests have some evidentiary value. What we need are more tests to identify what the relationship is between strength and testing rate. What can confidently be stated is that the faster the loading the lower the measured strength.

Surprisingly, wetting software does not lead to systematic knot strength losses. This is contrary to common expectations, thus this result is in need of direct testing. It is possible that the strength loss in software due to water saturation is simply less than the strength loss due to tying a knot in the software, in which case, knots may not change strength due to wetting. However, it is reasonable to expect knot strength to change in the presence of water because many knots fail by pinching and the associated heat produced, and heat production would be reduced in the presence of water. In short, this result is unexpected; further controlled studies are needed to determine the effect of water on knot strength in various software constructions and compositions.

Unsurprisingly, older and used equipment showed a loss of strength relative to new equipment. With such a small comparison sample it is impossible to determine if any relationships exist between age or use and strength, hence we need much more testing on old, used, and retired equipment to generate estimates of strength loss with age and use in knotted software. This means that testing old equipment is not only useful, but essential for answering some questions. Please send us your old equipment for testing!

While there is a limited data set for comparing the strengths of different compositions, it appears that knots in nylon are stronger than in polyester for the same sized material. Not enough data are available to quantify this relationship, therefore controlled testing is needed.

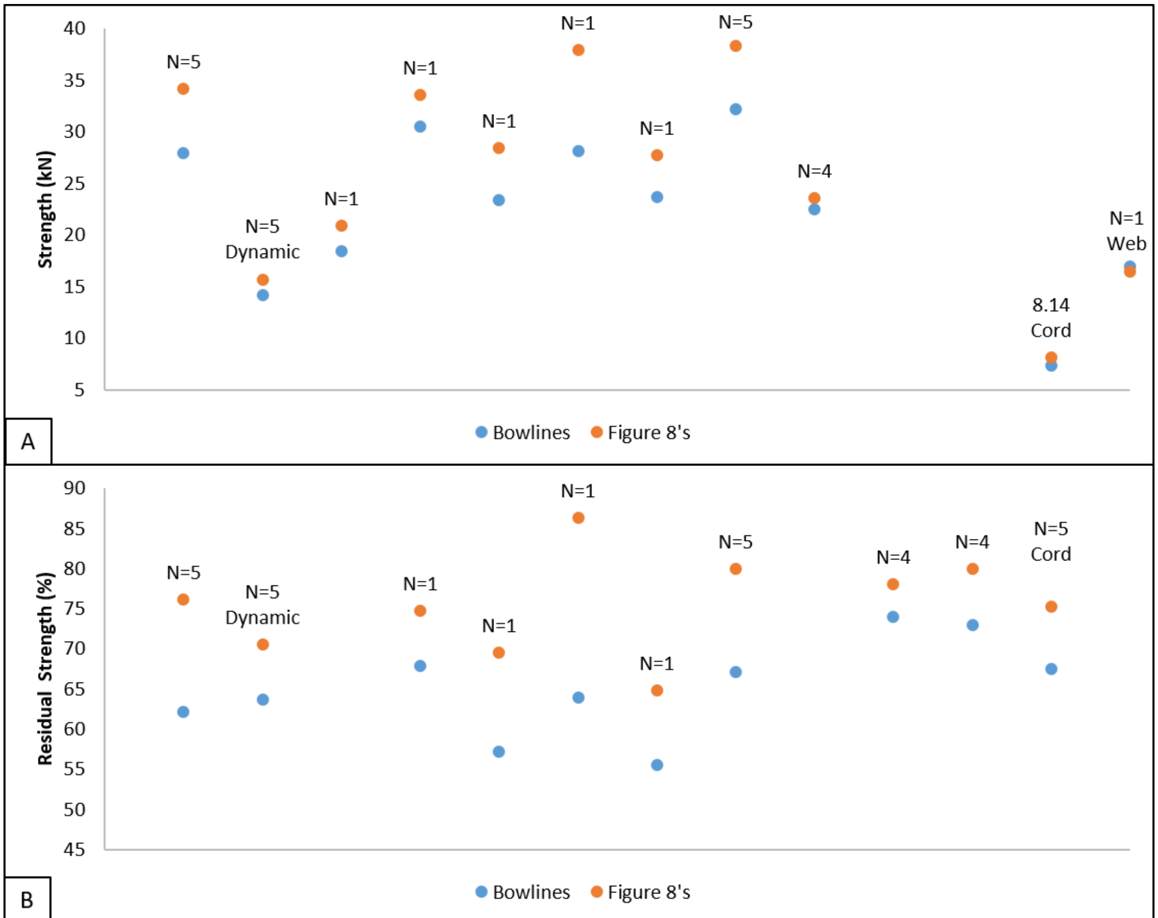

Figure 11: Comparative strengths of Bowlines and Figure 8 on a Bight knots. **A**) Studies reporting both Bowline and Figure 8 on a Bight strengths, and **B**) Residual knot strengths of Bowlines and Figure 8 on a Bight knots. Studies are plotted in the same order, so they can be compared between graphs.[8]

The data presented here does not determine whether bowlines or figure 8s on a bight are better, but it does provide a useful basis upon which to have an informed discussion. Bowlines are, on average, weaker than figure 8s on a bight, but their range of breaking strengths overlap (41.8-70.7% for bowlines, and 64.8-86.3% for figure 8s on the bight in rope, Figure 11b). Therefore some bowlines are stronger than figure 8s on a bight in the same material and size, meaning that it is simply false that bowlines are weaker than figure 8s on a bight in all cases. Similarly, assuming the same rope diameter, a bowline will be stronger in one composition (e.g., nylon) of rope of the same diameter as a figure 8 on a bight in another composition (e.g., polyester). So to say bowlines are weaker is an oversimplification. As a rigging community we need to acknowledge the complexity of rope systems and make informed choices. On average, bowlines are weaker, though sometimes they are as strong as or stronger than figure 8s on a bight. Ultimately the question is not which knot is stronger, but is the bowline strong enough to use? Objectively, it is just as strong as other life safety knots, and even stronger than some that are commonly used (Table 3). So relative knot strength alone is not a reason to not use the bowline.

What is abundantly clear is that there is a massive amount of knot testing data available, and more targeted testing is needed now that we have a decent idea of what are interesting avenues of research. The following studies would help clarify the trends observed here:

A. Knot strength tests with large sample sizes and controls to constrain variability in knot strengths.
B. Knot strengths in a variety of different sizes of software to determine if larger diameter rope and cord, or wider webbing, has lower residual knot strength, and by how much.
C. Controlled testing of knot strengths performed at different speeds to develop regression equations, which could help estimate strength loss due to rate of loading more realistically. This testing would also help clarify how to interpret the existing knot strength testing data.
D. Controlled testing of knot strength both dry and saturated with water to determine if there really is no consistent difference in knot strength when software is wet.
E. Controlled testing of knots tied in a variety of materials (e.g., nylon, polyester, Dyneema, etc.) and constructions (webbing, rope, cordage) to determine if the residual knot strength is the same or different between these variables.

Lastly, further "backyard" and "quick look" testing is essential to identify what variables are important to investigate with more targeted and controlled research. Please keep breaking gear and know that it is scientifically necessary and valuable!

Acknowledgements

This article was stimulated by a discussion with Bruce Parker at ITRS a few years ago. He commented that we do not need more prusik testing, but a synopsis of the data already available. I took this to heart and started collecting the testing data for knots and friction hitches for a few big review articles. The logical underpinning of this article was his idea, and he should get the credit for it. Sarah Truebe provided invaluable editorial advice and suggestions that improved the final product produced. All mistakes, content omissions, and grammar errors remain entirely the author's fault alone.

Table 1: Number of reported data points for the sixteen most commonly tested knots.

Knot	Total Number of Reported Data Points
Figure 8 on a Bight	288
Double Fisherman's Bend	109
Bowline	106+
Overhand Bend	81
Flat Overhand Bend	81
Overhand on a Bight	71
Girth Hitch	64+
Flat Figure 8 Bend	42
Butterfly (Bollard to Loop)	36
Butterfly (End to End)	36
Figure 8 Follow Through	31
Single Fisherman's bend	27
Figure 8 Bend	26
Clove Hitch	23
Scaffold Knot	21
Figure 8	21

Table 2: The number of tests reporting a given sample size. Most are 6 and lower.

Sample Size	Number of Tests Reporting the Sample Size
1	383
2	56
3	80
4	24
5	74
6	14
8	1
10	1
11	2
12	1

Table 3: Measured ranges of residual knot strength (R.K.S.) for knots in rope, loops of rope, cord, loops of cord, webbing, and loops of webbing.

Knot	Rope (End to End)		Rope (Loop)		Cord (End to End)		Cord (Loop)		Web (End to End)		Web (Loop)	
	R.K.S. (%)	# of Samples	R.K.S. (%)	# of Samples	R.K.S. (%)	# of Samples	R.K.S. (%)	# of Samples	R.K.S. (%)	# of Samples	R.K.S. (%)	# of Samples
Bowline	41.8-70.7	17			67.1	1						
Figure 8 (single in line)	49.2-56.1	3										
Figure 8 (two in line)	45.7-53.8	3										
Figure 8 On a Bight	64.8-86.3	7			39.9-91.8	5			61.0-86.2	5		
Figure 8 Follow Through	80.7	1							74.2	1		
Figure 8 End (Knot name unclear)	69.4-75.3	2			73.3	1						
Figure 8 On a Bight (End to End)	54.3-73.6	3										
Double Figure 8	66.1-82.4	3										
Inline Figure 8 (End to End)	48.2-58.7	3										
Inline figure 8 (Loop to End)	62.5-74.7	3										
Overhand on a Bight	84.6	1							65.0	1	51.3	1
Overhand Double Loop	73.8	1										
Butterfly (Loop to End)	60.7-80.6	5			72.0	1						
Butterfly (End to End)	59.2-68.8	3										
Barrel Knot (not a slip knot)	48.8-52.0	2										
Double Barrel Knot	57.8-61.7	2										
Slip Barrel Knot (Scaffold Knot)	68.5-81.3	2										
Double Slip Barrel Knot	73.8-83.2	2										
Girth Hitch											74.2	1
Figure 8 Bend	56.8-80.7	3										
Single Fisherman’s Bend	53.1-60.3	2			59.7	1						
Double Fisherman’s Bend	73.5-80.3	5	86.0-108.5	3	81.0	1	73.1-159.3	9			122.1	1
Triple Fisherman's Bend							72.0-163.1	16				
Sheet Bend	50.0-51.2	2			61.10	1						
Double Sheet Bend	54.6-54.7	2			57.3	1						
Butterfly Bend			99.9-105.8	2								
Overhand Bend (Water Knot)									63.8	1	140.2-157.8	2
Flat Overhand Bend			107.6	1								
Flat Figure 8 Bend			85.5	1								

[1] Data taken from nearly all citations listed were used in the compilation of this figure.
[2] Data taken from: Banquo 2010, danmerrick 2010, Drohan 2001, Evans 2015b,c, O'neill 2001, Powick Unknown Date d
[3a] Data taken from: Chamonix 2008, Drummond 1968, Drohan 2001, Meredith 1960, Parker Unknown Date, Powick Unknown Date A, Unknown Author 1998, Unknown Author Unknown Date, Weber 2001
[3b] Data taken from: Prohaska 1988
[3c] Data taken from: Bressan and Polato Unknown Date, DMM Climbing 2012a, Drohan 2001, superbenjaman 2001, Vogel Unknown Date
[4] Data taken from: Detter et al. 2008, Vines and Hudson 2004
[5] Data taken from: Hansen 2004, Unknown Author 2015a
[6] Data taken from: Bedogni and Guastalli 2004, Castro et al. 2010, DMM Climbing 2012a, Drohan 2001, Drummond 1968, McKently 2014, Moyer 1999, Richard Delaney 2015a,cUnknown Author Unknown Date,
[7] Data taken from: 20kN 2012, Bavaresco Unknown Date, Bedogni and Guastalli 2004, Boron et al. 2013, Chamonix 2008, Detter et al. 2008, Draughon 2004, Drummond 1968, erwright3 2011, Evans 2015b, Frank 1998, Guglielmo Di Camillo 2011a,b, Hansen 2004, Junghannb 2014, Martin et al. 2015, McKently 2014, Meredith 1960, Moyer 2000, NZcaver 2010, 2012, Prattley 2016, Richard Delaney 2012d, Schmidt and Clifford 2007, Unknown Author Unknown Date, Vogel Unknown Date, Zoppello 2014
[8] Data taken from: Frank 1998, Junghannb 2014, McKently 2014, Richards 2004, Sheehan 2004b, Storage 1992, Vines and Hudson 2004

Literature Cited:

20 kN, 2012, Webbing & threaded highline analysis w/strain gauge indicator (https://www.mountainproject.com/v/webbing--threaded-highline-analysis-w-strain-gauge-indicator/107533083)

20 kN, 2013, Destructive Testing: Webbing Termination Methods (http://www.mountainproject.com/v/edk-destructive-testing-of-different-diameter-ropes/108401408)

Avigamo, 2011a, Video-ensayo: Resistencia de nudos (http://www.foropicos.net/viewtopic.php?f=26&t=25140)

avigamo, 2011b, Ensayos de traccion I (nudo de gaza y ballestrinque) (https://www.youtube.com/watch?v=uKkuZ9xEvGU)

avigamo, 2011c, Ensayos de Traccion II (nodo gaza y nudo de cinta) (https://www.youtube.com/watch?v=ig3owtgMHds)

Banquo, 2010, Testing Marked Ropes to Failure (http://www.supertopo.com/climbing/thread.php?topic_id=1342794)

Bavaresco, Paolo, Unknown Date, Ropes and Friction Hitches used in Tree Climbing Operations, Treevolution (http://www.paci.com.au/downloads_public/knots/14_Report_hitches_PBavaresco.pdf)

Bedogni, Vittorio, Guastalli, Elio, 2004, Cordini per alpinismo: caratteristiche, problematiche e suggerimenti (1a parte), La Rivista del Club Alpino Italiano, Maggio-Giugno:84-90

Bedogni, Vittorio, Guastalli, Elio, Unknown Date, Cordini per alpinismo: carattaristiche, problematiche e suggerimenti (1a parte) (http://www.caimateriali.org/fileadmin/user_upload/vecchi/Bedogni,%20Guastalli%20-%20Cordini%20per%20alpinismo%20-%20La%20Rivista%20del%20CAI%206-2004.pdf)

Bigelmayr, Max, 2014, Climbing Ropes: Knot Break Tests (http://www.bigel-labs.de/3.Physik/Knots/web)

Born, Russ, 2000, Still in Search of a Reliable Belay, Proceedings of the International Technical Rescue Symposium 2000

Boron, K., Obstalecki, M., Kurath, P. Horn, G.P., 2013, Utilizing Knots to Reduce Dynamic Loads in Fire Service Rope Systems, Conference Proceedings for the Society for Experimental Mechanics Series 1, pp. 433-439

Bressan, di Giuliano, Polato, Massimo, Unknown Date, Longe e Daisy Chain: impieghi, Numeri di Alpinismo Unknown Volume:210-215

Brown, Alasdair, 2008, The Strength of Knots in Dynamic Climbing Rope, MEng Mechanical Engineering Technical Report

CAI CSMT, 2014, dvd csmt (https://www.youtube.com/watch?feature=player_embedded&v=j0LlIImcnUg)

CAI Scuola Franco Alletto, 2015a, CAI - Centro Studi Materiali e Tecniche (CSMT) (https://www.youtube.com/watch?v=zu_K-TD9T2U)

CAI Scuola Franco Alletto, 2015b, CSMT - Le "Longe" (https://www.youtube.com/watch?v=rVz7pVhIAe8)

Castro, Miguel, Jimenez, Manuel, Castro, Javi, 2010, Las cuerdas. Mira de que te cuelgas... (http://www.grupotriton.org/web/contenidos/Articulos/Resistencia%20Cuerdas/REsistencia_cuerdas.htm)

Centro Studi Materiali e Tecniche, 2013, Video Presentazione studio Longe (https://www.youtube.com/watch?feature=player_embedded&v=yo5o1voet-k)

Centro Studi Materiali e Tecniche, 2016, Longe study (https://www.youtube.com/watch?v=tDsK0cfZ8Ds)

Сергей Веденин, 2011a, Тест встречного узла, дайнема (https://www.youtube.com/watch?v=CtEvCnRnREY)

Сергей Веденин, 2011b, Тест узла восьмерка 2. (https://www.youtube.com/watch?v=SBDaGQBXWyY)

Сергей Веденин, 2011c, Тест узла восьмерка. (https://www.youtube.com/watch?v=YtA14DfiFIU)

Сергей Веденин, 2011d, Тест узла девятка. (https://www.youtube.com/watch?v=E1lWsGklx4Q)

Сергей Веденин, 2011e, Тест узла "половина грейпвайна". (https://www.youtube.com/watch?v=q8uv6zBuKLA)

Сергей Веденин, 2012, станции из репшнура (https://www.youtube.com/watch?v=t5UNyiax_44)

Chamonix, 2008, Series of Tests on Cow's Tails used for progression on semi-static ropes, Nylon Highway 53:39 pages

danmerrick, 2010, 12-9-2010 012.avi (https://www.youtube.com/watch?v=3Wr_vtR3DMk)

Detter, Andreas, Cowell, Chris, McKeown, Liam, Howard, Paul, 2008, Evaluation of current rigging and dismantling practices used in arboriculture, Health and Safety Executive, Research Report, RR668

DMM Climbing, 2011, How to Break Nylon and Dyneema Slings (https://vimeo.com/27293337)

DMM Climbing, 2012, Knotting Dyneema? (https://vimeo.com/39042545)

Draughon, Baron, 2004, PRM 426 Lab Test - Rescue Equipment - Test to Failure (http://www.whitewater-rescue.com/support/pagepics/rescuegeartest.pdf)

Drohan, David, 2001, Preferred Knots for Use in Canyons, at the bottom of the page is the article and all of the associated data (Reprinted in: Drohan, David, 2007, Preferred Knots for Use in Canyons, Nylon Highway 52:30 pages) (http://www.bwrs.org.au/?q=research)

Drummond, I., 1968, An Incident and Some Tests Concerning Sampson Rope For Prusiking, NSS News 26(8):114-116

Eric Campbell, 2009, Runner pull testing (https://www.youtube.com/watch?v=Nc5BN1UrKHI)

erwright3, 2011, Figure8breaktst2007 (https://www.youtube.com/watch?v=8_nU_HSqS8Y&index=2&list=PLp7NnyPOnqbAFzB1O6npA2FABvLBvL9lW)

Evans, Thomas, 2016, Strength Loss Due To Aging of 1 Inch Tubular Nylon Webbing (http://sarrr.weebly.com/sar3-original-research/strength-loss-due-to-aging-of-1-inch-tubular-nylon-webbing)

Evans, Thomas, 2015a, Is There a Right Way To Tie a Prusik? (http://sarrr.weebly.com/sar3-original-research/-is-there-a-right-way-to-tie-a-prusik)

Evans, Thomas, 2015b, Strength and Failure Mode of the Voodoo Tensioning System (http://sarrr.weebly.com/sar3-original-research/strength-and-failure-mode-of-the-voodoo-tensioning-system)

Evans, Thomas, 2015c, Response of Some 3:1 Haul Systems to Excessive Loading, International Technical Rescue Symposium, Portland, Oregon, November 5-8, 2015

Evans, Thomas, 2014, Empirical Breaking Strengths of Single Prusiks of Four Diameters on 11 mm Static Rope, International Technical Rescue Symposium, Denver, Colorado, November 6-9, 2014

Evans, Thomas, 2013, Empirical Observation of Anchor Failure Points in Old and Retired Webbing, International Technical Rescue Symposium, Albuquerque, New Mexico, November 7-10, 2013

Evans, Thomas, 2012, Implementing Example Research Methods at ITRS 2012 and Their Results, SAR^3 (http://sarrr.weebly.com/sar3-original-research/implementing-example-research-methods-at-itrs-2012-and-their-results)

Evans, Thomas, Stavens, Aaron, 2011, Empirically Derived Breaking Strengths for Basket Hitches and Wrap Three Pull Two Webbing Anchors, Proceedings of the International Technical Rescue Symposium, Fort Collins, Colorado, November 3-6, 2011

Evans, Thomas, Truebe, Sarah, 2015, A Review of Webbing Anchor Research, International Technical Rescue Symposium, Portland, Oregon, November 5-8, 2015

Evans, Thomas, Stavens, Aaron, McConaughey, Sherrie, 2012, Causal Mechanisms of Webbing Anchor Interface Failure and Failure Modes, International Technical Rescue Symposium, Seattle, Washington, November 1-3, 2012

Feryok, Zephyr, 2015, Is Light Right? Safe Highlines With Minimal Gear, Proceedings of the International Technical Rescue Symposium 2015

Frank, James, 1998, CMC Rope Rescue Manual, Third Edition, CMC Rescue, Inc. Santa Barbara, California

Giorgio Fiori, 2014a, Anchorage srt, knots test. (https://www.youtube.com/watch?v=QEwepKiLRIY)

Giorgio Fiori, 2014b, TEST on SRT ANCHOR with FRICTION SAVER (https://www.youtube.com/watch?v=VKmbcU69b7k)

Gommers, Mark, 2014, An Analysis of Bowlines, Nylon Highway 59:32 pages

Guglielmo Di Camillo, 2008, TECNICHE E MATERIALI SPELEO ALPINISTICI 3o parte (https://www.youtube.com/watch?v=GjB2i46CS3Y)

Guglielmo Di Camillo, 2011a, Tecnica e Materiali a Padova 2011 - Trazione lenta (Video 1 - Parte 2) (https://www.youtube.com/watch?v=zWG0I9-QF38)

Guglielmo Di Camillo, 2011b, Tecnica e Materiali a Padova 2011 - Trazione lenta (Video 1 - Parte 1) (https://www.youtube.com/watch?v=PFtraAmW2eg)

Guglielmo Di Camillo, 2011c, Tecnica e Materiali a Padova 2011 - Trazione veloce (Video 2o) (https://www.youtube.com/watch?v=LeNf9u6AKmg)

Hansen, Douglas, 2004, A Look at Knot Strength in a Dynamic Situation, Proceedings of the International Technical Rescue Symposium 2004

Hansen, Douglas, 2005, What Is Your Real Safety Margin, Proceedings of the International Technical Rescue Symposium 2005

Harness destruction testing, 2011a, break in the knot analysis (https://www.youtube.com/watch?v=hVY8vomYVa8)

Harness destruction testing, 2011b, spectra knot undoing (https://www.youtube.com/watch?v=xZoF2VAE3zU)

Harness destruction testing, 2011c, readers digest version of multiple weather exposed spectra climbing slings tests.wmv (https://www.youtube.com/watch?v=QNpZ8mFOZmM)

Harness destruction testing, 2011d, Yosemite finish tie in 2 (https://www.youtube.com/watch?v=GVF_eicSBMY)

Helga Sanna, 2010, Esperimento: test tenuta delle corde (https://www.youtube.com/watch?v=n2uleq_8Pu8)

Hundal, Geir, Unknown Date, The Climbing Mythbusters (http://www.geir.com/mythbuster.html)

Jeffrey, Darren, McDaniel , Travis, Santillan, Gavin, 2010, Canyoneering Anchors and Basic Rope Systems, AuthorHouse, Indiana, pg. 94-95

Jones, Tom, 2002, Girth hitching slings to the cable on wired nuts (http://www.paci.com.au/downloads_public/knots/11_Tests_Girth-hitched_slings_2002.pdf)

Jones, Tom, 2005, Some Knot Testing Data (http://canyoncollective.com/threads/some-knot-testing-data.7688/)

Junghannb, Stefan, 2014, Webbing Strength in Anchors (http://slacklab.de/en/rigging/strength-of-webbing-anchors)

Luscinski, Keith, 2015, Knotted vs. Sewn Terminations in Cow's Tails, Proceedings of the International Technical Rescue Symposium 2015

made in mountain, 2015, Ballestrinque: Desliza o se rompe? (https://www.youtube.com/watch?v=VjsRsbLBH-Y)

Mammut Sports Group, 2007, Report on the breaking of a girth-hitched sling, with recommendations for usage of connected slings (http://www.riverrescue.it/download/girth_hitch_report.pdf)

Martin, Daniel, A., Boron, Kevin, Osbstalecki, Kurath, Peter, Horn, Gavin P., 2015, Feasibility of Knots to Reduce the Maximum Dynamic Arresting Load in Rope Systems, Journal of Dynamic Behavior of Materials 1:214-224

Matteo Will Bertolotti, 2013, ROTTURA/SCIOGLIMENTO NODI SU CORDINI A TRAZIONE LENTA (https://www.youtube.com/watch?v=vtVcWBfCGkY)

McDonald, Mike, 2005, Backyard Testing: Pitfalls, Pratfalls and Things That Go Bump in the Night, Proceedings of the International Technical Rescue Symposium 2005

McKently, John, 2014, Rescue Knot Efficiency Revisited, Proceedings of the International Technical Rescue Symposium 2014 (Reprinted in: McKently, John, 2014, Rescue Knot Efficiency Revisited, Nylon Highway 59: 6 pages)

Meredith, Irving, 1960, Climbing Rope Tests, American Alpine Journal 12(1):191-194

Moyer, Tom, 1999, Pull Tests of the "Euro Death-Knot" (http://user.xmission.com/~tmoyer/testing/EDK.html)

Moyer, Tom, 2000, Pull-Testing at the MRA Intermountain Recert (http://user.xmission.com/~tmoyer/testing/pull_tests_7-00.html)

Moyer, Tom, Tusting, Paul, Harmston, Chris, 2000, Comparative Testing of High Strength Cord, Proceedings of the International Technical Rescue Symposium 2000 (Reprinted in: Moyer, Tom, 2004, Comparative Testing of High Strength Cord, Nylon Highway 49: 11 pages)

NZcaver, 2010, Rope rescue knot failures (https://www.youtube.com/watch?v=WNyilCyqJyE)

NZcaver, 2012, Breaking Gear NCRC 2012 (https://www.youtube.com/watch?v=4LYJO3QHjos)

O'Neill, Collin, 2001, Slow-Pull Testing of the "Double Overhand On Itself" Tie, Nylon Highway 46:8 pages, and in pdf here (reprinted in the Speleo Digest 2000:386-388)

OTE Rescue, 2014, Rigging Myths (https://www.youtube.com/watch?v=vCb7e7bSNHc&list=TL1KirjmFQGEsxMTEwMjAxNQ&index=10)

Parker, Robert, Unknown Date, Use and Abuse of the Clove Hitch (http://www.guidetricksforclimbers.com/index.php/appendix/78-gtc-articles/78-use-and-abuse-of-the-clove-hitch)

Powick, Kolin, Unknown Date a, What is the Strongest Rappel Knot? (http://blackdiamondequipment.com/en_US/qc-lab-what-is-the-best-rappel-knot.html)

Powick, Kolin, Unknown Date b, Sharpie for Marking the Middle of a Rope? (http://blackdiamondequipment.com/en/qc-lab-can-i-use-a-sharpie-to-mark-the-middle-of-my-rope.html)

Powick, Kolin, Unknown Date c, Connecting Two Slings Together (http://blackdiamondequipment.com/en/qc-lab-connecting-two-slings-together.html)

Powick, Kolin, Unknown Date d, Retiring Old Ropes (http://blackdiamondequipment.com/en/qc-lab-retiring-old-ropes.html)

Prattley, Grant, 2014a, A knot that drives you around the bend! (http://oterescue.com/project/sheet-bend-compared-bowline-knot/)

Prattley, Grant, 2014b, Rigging Myths and other things rope (http://oterescue.com/project/rigging-myths/)

Prattley, Grant, 2016, Which Bend For Joining Ropes? Testing and analysis of flat bends used for rope retrieval (http://oterescue.com/project/which-bend-for-joining-ropes/)

Prohaska, Heinz, 1988, A Safer Bowline for Climbers and Cavers, Nylon Highway 26:4-5

Richard Delaney, 2012a, EDK plus extra overhand knot Edelrid 11mm dynamic (https://www.youtube.com/watch?v=8T_xmrts9v4)

Richard Delaney, 2012b, Figure-of-8 vs. Bowline (https://www.youtube.com/watch?v=9skZ27YQd1g)

Richard Delaney, 2012c, Sterling htp 11.1mm rope: figure-of-8 knot against bowline (https://www.youtube.com/watch?v=T1ZosDmBntE)

Richard Delaney, 2015a, Figure 8 Bunny Ears knot test (https://www.youtube.com/watch?v=P5qDr3qYZ9o)

Richard Delaney, 2015b, "EDK": overhand & fig8 pull test (https://www.youtube.com/watch?v=QGqGlFc3oFs)

Richard Delaney, 2015c, Figure-of-8: 75% or 50% (https://www.youtube.com/watch?v=sFWShgPh4gM)

Richards, Dave, 2004, Knot Break Strength vs. Rope Break Strength, Proceedings of the International Technical Rescue Symposium 2004 (Reprinted in: Richards, Dave, 2005, Knot Break Strength vs. Rope Break Strength, Nylon Highway 50:9 pages)

Rich Carlson, 2015, EDK in Webbing? (http://www.canyoneering.net/edk-in-webbing/)

SARRR, 2015, Slow Pulling a Webbing and Cord Girth Hitch (https://www.youtube.com/watch?v=DEPPP9NF_lw)

Schmidt, David, Clifford, David, 2007, Busted! A test of the breaking strengths of five common knots, Sail Magazine February 2007:82,84-85

Sheehan, Alan, 2004a, Load Testing http://www.paci.com.au/downloads_public/knots/08_Tests_OberonSES_29July04.pdf

Sheehan, Alan, 2004b, Load Testing, NSW SES Vertical Rescue Professional Development Workshop, Wellington NSW, August 14, 2004 http://www.paci.com.au/downloads_public/knots/07_Tests_OberonSES_14Aug04.pdf

Smith, Bruce, 1986, Which is Stronger? Nylon Highway 22:14

Smith, Bruce, 1995, Myth Busting, Nylon Highway 39:6-11

Storage, William, 1992, Slippery Ground and Undercurrents, NSS News 50(5):132-134

superbenjaman, 2011, Prueba de rupture de equipo de escalada tirolesa cable tensor polea mosqueton (https://www.youtube.com/watch?v=ABP5eOH_wWc)

top_rope, 2014a, Marlow 8mm Viper Prusik Cord Test - TREE SURGERY ARBORISTS (https://www.youtube.com/watch?v=alFTfnlTRt4&feature=youtu.be)

top_rope, 2014b, TEST of MARLOW Viper 8mm eye2eye LANYARD ROPE PRUSIK (https://www.youtube.com/watch?v=V9VbwO6th5I)

unjoan, 2016a, Nudo JOANET o Nudo Juanito (La revolucion) (https://www.youtube.com/watch?v=exkRJzS_zAE&feature=youtu.be)

unjoan, 2016b, Pruebas de Resistencia del Nudo JOANET o Nudo Juanito (Algunas de las pruebas realizadas) (https://www.youtube.com/watch?v=TzWhlJxLZVI)

Unknown Author, 1998, 19980912-TER, Static Ropes, IKAR Terrestrial Rescue Commission (document in German) (http://www.alpine-rescue.org/ikar-cisa/documents/2007/Statikseile_980912.pdf)

Unknown Author, 2006, Spectra Knots (http://electricant.net/beta/spectra/spectra_knots.htm)

Unknown Author, 2009, Random Rope and System Testing (http://www.advancedrescue.com/resources/FFD-Rope-testing.pdf)

Unknown Author, 2015a, Webbing Knots (http://rope-work-101.wikidot.com/webbing-knots)

Unknown Author, 2015b, Sheet Bend Testing (http://rope-work-101.wikidot.com/sheet-bend-testing)

Unknown Author, 2015c, Offset Bound Overhand Bend Testing (http://rope-work-101.wikidot.com/offset-bound-overhand-knot-testing)

Unknown Author, Unknown Date, Swiftwater Rope Testing - Wet and Dry Rope Strength (http://www.swiftwaterrescue.at/content/info/rope-test1.html)

Vickers, Pete, 2006a, Belay & Brake Device Loading Evaluation (http://www.kajakksenteret.no/files/Belay%20and%20brake%20loading%20test.pdf)

Vickers, Pete, 2006b, Throwline tensile strength Investigation (http://www.kajakksenteret.no/files/Throwline%20loading%20test.pdf)

Vines, Tom, Hudson, Steve, 2004, High Angle Rescue Techniques, Third Edition, Mosby, St. Louis, pg. 69

Vogel, Todd, Unknown Date, Knot and cord strength: answers to common questions (http://efclimbers.net/wp-content/uploads/2013/02/Knot-and-cord-strength.pdf)

Weber, Chuck, 2001, Fall Factors & Life Safety Ropes: a closer look, Proceedings of the International Technical Rescue Symposium 2001

Zoppello, Cristiano, 2014, Le longe in arrampicata, speleologia e torrentismo (http://www.caimateriali.org/fileadmin/user_upload/pdf_marra/convegno_Predazzo/Le_Longe_in_arrampicata__speleologia_e_torrentismo.pdf)