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BASIC PRINCIPLES OF FORENSIC KNOT ANALYSIS: A QUALITATIVE STUDY OF TYING BEHAVIOUR

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Abstract

The knot-tying behaviour of thousands of subjects was observed over a period of 25 years. A number of key principles applicable to forensic knot analysis emerged, most of which have been confirmed by other studies. Most notably, tying behaviour is consistent and reproducible. Basic knots – like Overhand Knots, Half Hitches and Half Knots – are chiral, and individual knot tiers produce one mirror-image version more so than the other. This tendency can be influenced by a number of factors, such as the number of available working ends, tying position, interference, the creation of slip loops, and wend switching. These principles can guide investigators in the forensic analysis of knotted evidence and point to future avenues of research.

Keywords: Forensic science; knots; tying behaviour; handedness; mirror-image knots; analysis principles

Overview

Crime scene investigators have been examining knots and ligatures for at least a century, and the process of properly preserving knotted evidence and correctly identifying knots is generally understood. However, the fundamental principles of analysis – which assist in deriving informed and useful opinions – have been rarely articulated in a clear and systematic manner. Evidentiary-based conclusions have been a matter of tradition, experience and intuition without the benefit of consistent and confirmable guidelines (Budworth 1985; Chisnall, 2000, 2007; Hazelwood, Dietz & Burgess, 1981).

The purpose here is to identify a number of key phenomena that relate to fundamental tying behaviour, based on thousands of qualitative observations. The study described evolved from an informal endeavour into a 25-year process of opportunistic observation and evaluation to establish general principles and to discover exceptions to these principles. Further, these qualitatively-derived principles are supported by empirical evidence.

Terminology and Concepts

Unfortunately popular knotting terminology has not been entirely consistent over the years. Nomenclature varies from country to country and various authorities differ. In an effort to standardize names and bring meaning and precision to the study described, a brief overview of essential terms is required. These originate from a variety of sources, including Ashley (1944)[1] and other knotting references, norms established by The International Guild of Knot Tyers[2], and a number of peer-reviewed papers in forensic science (Budworth, 1985; Nute, 1986; Chisnall, 2007, 2009, 2010).

The terms wend, stand and bight are applied as follows. A 'wend' is a working end employed to tie a knot. The 'stand' is the standing part or long, unknotted portion of the rope or cord. The 'bight' is that portion of rope or cord forming the knot proper.

Strictly speaking, the term knot refers to a tangled mass in a rope, such as an Overhand Knot (Figure 1) or Figure Eight Knot (Figure 2).

Figure 1. Overhand Knots (S left, Z right)



[1]The Ashley Book of Knots, a classic tome on general knot craft, is considered by most knot afficionados to be the "knot Bible" or best general knotting reference.

[2]The International Guild of Knot Tyers was founded in Great Britain in 1982. Its global membership includes amateur knot enthusiasts (hobbyists, hikers, campers, sailors, cavers, climbers, etc.) and those who have a professional interest in the practical and theoretical aspects of knots (instructors, riggers, rescue personnel, surgeons, topologists, anthropologists, chemists, forensic investigators, and so forth). The mandate of the IGKT is "to promote the art, craft and science of knotting, its study and practice; to undertake research into all aspects of knotting; and to establish an authoritative body for consultative purpose." It produces a regular publication entitled Knotting Matters. The forensic analysis of knots and ligatures has not been one of this association's principal concerns.

Figure 2. Figure Eight Knot (Amphichiral)



A bend is a knot joining two wends, like the Water Knot (Figure 3).

Figure 3. Water Knot (S top, Z bottom)



There are certain bends – for example, the Reef Knot (Figure 4) – that are used to secure the wends of rope or cord wrapped around a parcel or bundle.

Figure 4. Reef Knots (S/Z top, Z/S bottom), consisting of two opposite Half Knots



A loop or loop knot, as the name suggests, is a knotted ring of rope or cord. This includes formations like Overhand Loops (Figure 5) and Bowlines (Figure 6).

Figure 5. Overhand Loops (S left, Z right)



Figure 6. Bowlines (S left, Z right; or 'b' and 'd', respectively)



A loop knot can consist of one or more immovable or sliding loops. The basic Overhand Slip Loop is an example of the latter (Figure 7).

Figure 7. Overhand Slip Loops (S left, Z right)



A hitch, like a Girth Hitch or Clove Hitch (Figure 8), is used to secure a line to some external object. The difference between a loop and a hitch is related to structural integrity. If a loop is removed from the object to which it is attached, the knot retains its structure. If a hitch is removed from where it is secured, it falls apart.

Figure 8. Clove Hitches (S/S left, Z/Z right) and a Girth or Cow Hitch (center, S Half Hitch left, Z Half Hitch right; amphichiral if the wend and stand are not differentiated), consisting of two Half Hitches each.



There are specialized hitches, like the Prusik Knot or Hitch (Figure 8), which are used to attach a cord to a thicker rope and grip it securely.

Figure 9. Prusik Knot or Hitch (six wraps or turns; amphichiral; structurally similar to the Girth Hitch)



A quick scan of any well-known knot reference indicates there are a multitude of specialized and esoteric knots with equally esoteric names. Most people in the general population do not tie sophisticated knots (Chisnall, 2000, 2010). Specialized knots are utilized in specific recreational and occupational activities, like sailing, climbing, macramé and vertical rescue. Simple knots are encountered most frequently in general tying practices and in case evidence (Chisnall, 2010). These are tied innately and the ability to tie simple knots is acquired when people are very young (Piaget, 1929/1951, 1948/1967).

Some knots are amphichiral, like the Figure Eight (Figure 2), because they have no mirror images. Others have mirror images or enantiomers and are therefore labelled chiral. The terminology for chiral knots, like the Overhand Knot, Half Hitch and Half Knot, is 'S' and 'Z' (Figures 1, 10, 11). This is consistent with textile standards and anthropological terminology, and the S and Z designations have been established in the forensic literature (Canadian Government Specification Board, 1978; Canadian General Standards Board, 1986; Wendrick, 1996; Chisnall, 2000, 2010; Spörri, 2008). The labels 'l' and 'd' – which are equivalent to S and Z, respectively – are used in Great Britain (Ide, 2009) and there have been other less popular and more ambiguous labelling systems.

Figure 10. Half Hitches (S left, Z right)



The basic chiral knots of interest here are Overhand Knots (Figure 1), Half Hitches (Figure 10), Half Knots (Figure 11), Overhand Loops (Figure 5), Overhand Slip Loops (Figure 7), Granny Knots (Figure 12) and Reef Knots (4). The Granny and Reef Knots comprise two equal or opposite Half Knots, respectively. The reason for focussing on these particular formations is because knotted evidence is dominated by simple, unsophisticated knots (Chisnall, 2000, 2010).

Figure 11. Half Knots (S top, Z bottom)



Figure 12. Granny Knots (S/S top, Z/Z bottom), consisting of two identical Half Knots each



Method

The study procedure was simple and fundamentally informal. There was no structured format to the data collection in that subjects were not asked to perform a series of standardized knotting tasks. Subjects were observed tying knots in everyday situations and during specialised training sessions. An array of tying situations and tasks requiring knots furnished rich opportunities for unobtrusive observation. These included shoelace and parcel tying, lashings, erecting tents, securing boats to docks and canoes to trailers, learning the Water Knot (whose fundamental structure is based on the simple Overhand Knot; Figure 3) and the Reef Knot (which consists of two opposite Half Knots; Figure 4), yard and gardening tasks, household storage and maintenance tasks, belt and strap tying, and many other commonplace or outdoor applications.

Repeated observations served to establish recurring patterns and trends or revealed exceptions to emerging principles. These qualitative observations commenced in 1983, the year I was first contacted to examine knots and ligatures acquired from crime and death scenes, and qualitative observations are ongoing. However, with regard to the principles reported here, that investigation proceeded until 2008.

Many individuals and hundreds of small groups were observed over a period of 25 years, as summarized in Table 1.

Table 1. Groups Observed

Description of Subjects	Tying Task Contexts	Approximate Number of Individuals Observed
Boys and staff aged seven to mid-twenties from a residential boys camp	Learning knots, participating in camping and related activities	2,000
Members of a university climbing club	Learning knots and participating in outdoor and indoor climbing activities	3,000
Members of a university outdoors club	Learning to tie and apply new knots	500
Firefighters and police attending training sessions	Learning to tie and apply rope access and rescue knots	500
Random individuals tying knots in the course of their regular work and play	Household maintenance, gardening, parcelling tasks, tying belts, etc.	More than 1,000

In particular, the intrinsic behaviour of people performing the most basic tying tasks was observed repeatedly. Particular attention was paid to tying habits and repeatability, knot chirality, tying material, tier position, and other contextual factors. What follows is a summary of the recurring behaviours and trends that were observed.

Findings and Significance: Principles of Analysis

Several key principles or analysis guidelines emerged out of these behavioural observations, many of which have been corroborated by informal and peer-reviewed empirical research and case work (Budworth, 1985; Nute, 1986; Chisnall, 2000, 2007, 2009, 2010).

- All factors being equal, tying behaviour is consistent and reproducible. People tend to tie the same kinds of knots and the same specific knot structures out of habit.
- When performing basic tying tasks (Overhand Knots, Half Knots and Half Hitches, whether S or Z) knot tiers tend to tie one enantiomer more often than its counterpart. In fact, many people produce either S or Z Overhand Knots, Half Knots and Half Hitches exclusively or almost exclusively. Tiers find it difficult, very difficult or impossible to deliberately reverse the chirality of their knots.
- Some tiers consistently produce one enantiomer more often than the other, whether tying with one or two wends. Other tiers, however, exhibit different behaviour. One enantiomer dominates their one-wend tying habit while the opposite dominates their two-wend tying habit.
- Switching wends – that is, putting the left wend in the right hand and right wend in the left hand – has a tendency to reverse knot chirality.
- Interference – such as pre-existing knots and excessively long wends – may reverse knot chirality. The size and stiffness of tying materials does not appear to have a consistent effect on basic tying habits.
- Tying in awkward positions, as when tying overhead, may cause a reversal of chirality.
- Initiating and terminating a series of Half Hitches may be characterized by reverse chirality.
- The tying of slip loops and bows – as when securing shoelaces – can cause reverse chirality.
- Declared knowledge of the Reef Knot or demonstrated experience with more sophisticated knots – such as the Bowline[3] and Figure Eight Knot – does not mean the tier will necessarily produce proper Reef Knots out of habit.
- Once again, most people tie unsophisticated knots. This is corroborated by case evidence as well as empirical data.

[3]Bowlines are also chiral. According to their internal structure they can be designated as either S or Z, or ‘b’ or ‘d’. The latter labels should not be confused with the British ‘l’ and ‘d’ system of nomenclature for Overhand Knots, Half Hitches and Half Knots. These labels are specific to Bowlines and Sheet Bends (not illustrated).

· It appears the S enantiomer occurs more frequently than the Z enantiomer in basic knot-tying tasks throughout the general population.

Each of these principles should be kept in mind when looking for consistent patterns and similarities. This is especially important when comparing similar or identical knots from the same crime scene, and when attempting to match crime scene knots to suspect samples. Specifically, the context, the number of working ends, the tying sequence, the tier's likely position, the tying task and purpose, and any potential interference must be considered.

These fundamental principles can be verified by anyone possessing basic knotting ability through careful experimentation and observation. No doubt there are subtler and more complex knotting principles still awaiting discovery, and these could be useful to forensic knot analyses in the future.

Conclusions

Key principles of analysis emerged out of qualitative observations, and many of these principles have been confirmed informally or empirically. In forensic science, beyond the basic preservation of knotted ligatures and the exact identification of knotted structures, these guidelines should be subsequently applied to an analysis of the tying process, the function of those knots, and any comparison made between crime scene knots and suspect samples.

Knot-tying behaviour embodies a complex set of phenomena. It is a subtle undertaking to model and explain tying behaviour. For the time being, the set of guidelines outlined herein serves as what physicists might call an 'effective theory' – a set of principles that currently fits observations without identifying or defining all underlying mechanisms (Hawking & Mlodinow, 2010). Until such time as future research, observations and case work uncover fundamental processes and necessitate modifications or fine-tuning, the reported phenomena offer a foundation of key assumptions to the forensic analysis of knots.

These principles, coupled with data from empirical research, could be harnessed to make group- or class-characteristic statistical assessments concerning crime scene evidence relative to suspect samples and the essential behaviour of the knot tiers involved.

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