The Perceptual Skills of Tying Knots

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by

Selby Redman Schwam

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The Perceptual Skills of Tying Knots

This study examines the possible perceptual influences on learning to tie knots. Research included two experiments; one focusing on behavioral observation and the second focusing on the possible influences of differentiation training and knowledge of results on tying knots.

Experiment 1 was a behavioral observation. Participants were asked to tie four knots: a sheetbend knot, a square knot, a figure 8 knot, and a bowline knot. They were given a model of each knot and then asked to attempt to try and tie a replica. Participants were given five trials per knot which were timed to measure improvement in learning.

Results showed that with time participants get better and faster at tying knots. Statistics showed that over the five trials, the time it took to tie each knot decreased. As the knots grow more complex, the time taken to tie each knot increased.

Participants showed several common behavior patterns. Participants spent quite some time studying each knot model before any attempt was made to tie a knot. Tracing the models with their fingers was a frequent behavior among participants, suggesting that an initial step in learning to tie knots was to differentiate perceptually the patterns of strand crossings for knots

Experiment 1 suggested that psychological processes involved in learning to tie knots are at least in part perceptual.

Experiment 2 examined the influence of knowledge of results and differentiation training on learning to tie knots. Knowledge of results was used because it is known to be helpful in learning to tie knots. Differentiation training was used because it appeared useful to study the effects of discriminating knot patterns on the ability to tie knots.

Participants were divided into four groups. Two of the groups were given differentiation training, one with feedback on knot-tying trials and one without feedback on knot-tying trials. Differentiation training consisted of participants discriminating between a target knot pattern and other patterns. The other two groups were given articles to read in place of the differentiation training, one with feedback on knot-tying trials and one without feedback on knot-tying trials.

All participants were asked to attempt to tie a square knot. Each attempt was timed and notes on behavior were taken.

Results showed that within the differentiation training, times to judge the correctness of patterns improved across blocks. Again, with practice participants got better at tying knots. Differentiation training and knowledge of results had little influence on the improvement of knot-tying skills. Analysis of the data without the data from individuals who reported prior knot-tying experiences did not alter the pattern of results.

This study could be a step in further research towards the question of how people go about tying knots because it at least found that differentiation and knowledge of results have very little effect on the skill of learning to tie knots, under the conditions used. Future research should study other variables that may influence knot-tying. Perhaps in other variables lie the missing piece to the puzzle of how people learn to tie knots.

Table of Contents

1. General Introduction....2

2. Literature Review....5

3. Experiment 1....11
   Introduction....11
   Methods....11
   Results....15
   Discussion....18

4. Experiment 2....20
   Introduction....20
   Methods....21
   Results....27
   Discussion....32

5. General Discussion....34

6. References....37

Table of Figures

1. Trefoil Knot..4

2. Knots used in Experiment 1...13

3. Mean times to tie each knot in each trial of Experiment 1.................16

4. The six crossovers of a square knot..23

5. Possible square knot patterns..25

6. Times for differentiation trial blocks...28

7. Mean times to tie correctly on criterion trials.....................................29

8. Results of Experiment 2...31

Although humans have been tying knots for over 26,000 years, we know little about the psychological processes that knot-tying requires (Bower, 1995).

Evidence exists that ancient civilizations placed great importance on knotted ropes. Near the Sea of Galilee strands of plant fibers were found near the bones of fish, suggesting that the fibers were part of bags or nets that stored the fish. If so, some type of knot had to be used in order to secure the fibers together ("Strands of," 1994). In ancient Peru, the use of knots is evident in the remnants of *quipus*, knots on various colored strands (Berreteaga. 1991). The quipus were used as a counting system and as a language to document important events in Peruvian history. Barber (1994) points out that as far back in time as the Bronze Age there is evidence in burial tombs of knots being tied. Clothing on mummies has been found well preserved, including skirts and belts that when worn required one to wrap the article around the waist and cinch it with a knot. Furthermore, the way the clothing was made suggested knot usage. Weaving was not yet in practice so clothing was made by twisting plant or animal fibers into string and knotting many strands together. Even today, of course, crocheting and knitting are essentially using knots to create fabrics.

In the present, we use knots so often we take them for granted. What would we use to fasten things if we did not have knots? Knots are used in recreational activities like rock climbing, horseback riding, and sailing (Leeming, 1940). The military uses knots when packing parachutes, laying down the perimeters of campsites, and when tying down vehicles when they are being carried by aircraft (U. S. Army, 1992). Hobbies like quilting, macramé, and sewing require knowledge of knot-tying (Leeming, 1940).

An important use of knots today is in the medicine. Doctors use square knots when tying off surgical stitches. A continuous suture is used to close off a wound and each stitch is knotted individually for minimal scarring (Horton & Smart, 1986). A Connell suture places the knots on either ends of the wound but, on the inside of the injury. A Halstead suture is a stitch sewn parallel to the wound tied with one knot. Without the knot used to tie off the suture, wounds would not heal properly (Melloni, 1993).

What exactly is a knot? According to Menasco and Rudolph (1983), the mathematical definition of a knot is a closed curve in three-dimensional space. That means it has no free ends. The curve may pass over and under itself, but must not connect when it intersects. This is easy to visualize. Imagine a piece of rope, knot it, and attach the ends together. If the knot can not be untied to form a circle, mathematically it is a knot. The simplest knot is a trefoil shown in Figure 1 (Skerrett, 1994). From there knots get progressively more complex. The more crossings of the curve over and under itself, the more complex the knot. To date there are 12,965 known knots (Skerrett, 1994).

The mathematical study of knots was initiated by physicist William Thompson (Peterson, 1992). Thompson developed an idea about the way matter is structured. He proposed that atoms of different elements were shaped like knots with the ends fused together to keep them from breaking apart. Another physicist, Peter Tait, felt there was some sense in the theory and went to work developing a table of knots, to show the different types of known knots (Peterson, 1992). Tait designed the first working knot chart. The mathematics involved with knot theory is very abstract and only in recent years have mathematicians had much success understanding knots. Adams (1994) provides an introduction to some basic concepts of knot theory. In 1990, to ease the

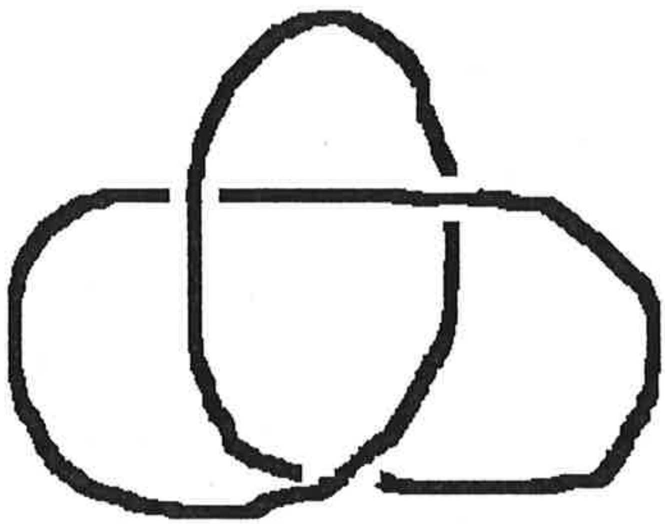


Figure 1. Trefoil Knot

complexity of knot identification, Victor Vassiliev discovered a new way to look at knots. He proposed that if two knots are equivalent to each other, then there is a way to manipulate each knot, without untying it completely, so it becomes the other knot. This new outlook is allowing scientists to study the way knots fit together in groups (Peterson, 1992).

This new way of studying knots does not completely solve the problems mathematicians are working on. Mathematicians are curious about whether two knots that look different may actually be the same knot, just manipulated a different way. In fact, the new method is not even easily understood by experts in the field. While scientists work on the academic problem of knot theory, practical uses for mathematical knot theory in applied areas are being found.

Some of the most interesting applications are in biology, chemistry, and physics. Knots can be represented by equations. For example, these equations and the body's processes for breaking apart DNA and recombining it are very similar in process. Scientists can mathematically name knots they see in the DNA strands, work out the logical order in which the body cuts and recombines each strand, and look more accurately at the combinations for study. These knot equations also allow researchers to find new configurations of DNA by analyzing the equations to find hints about knots not yet found. This is accomplished by estimating how many crossings are in the knot (Peterson, 1988).

A careful examination of the psychological research literature reveals that very few investigators have looked at the behavioral characteristics of tying knots. In general where knots have been used they were selected as stimulus materials in studies of a range of processes, but the process of tying knots itself apparently has not been studied. However, some sources (Cassidy, 1985) acknowledge that learning to tie knots is not easy.

Hayes and Henk (1986) focused on knot-tying as a means to examine how well participants comprehended passages they had to read. The researchers were interested in how well subjects remembered complex directions. The hypothesis was that having illustrations supplementing difficult text made it easier to remember content. High school students were given instructions for tying a difficult knot. Later, they were asked to tie the knot from memory. Results showed that text plus pictures allowed for better recall and that text by itself gave worse memory recall results. In the studies presented in the present paper, participants were also asked to tie knots after studying pictures.

Printed sources attempting to teach knot tying rely heavily on pictures, of course (Bigon & Regazzoni, 1981; Budworth, 1985; Shaw, 1960), and they must work to some degree.

Moreno (1991) assessed the verbal behavior of White and Native American mothers instructing their children on how to tie their shoelaces. The mothers were asked to give their children specific directions on how to tie their shoelaces. White mothers gave instructions that were said to contain more perceptual questioning of their children than the other mothers. Native American mothers were more controlling of their children, doing more of the physical work involved for their children. The study found the ethnic differences in instruction, even taking into account the level of schooling of the mother. This finding is important to the present studies because it suggests that differences in training approaches can alter knot-tying performance.

Biederman, Ryder, Davey, and Gibson (1991) asked whether passive observation or interactive modeling was better when teaching life skills to developmentally impaired children. Tasks like shoe tying and hair combing were used as trainable behaviors. The participants were videotaped while performing the behaviors. University students rated the behaviors from the video and judged that performance had faster improvement with the tasks trained passively than the actively trained behaviors. One reasonable implication of this result is that perceptual experience by itself can improve knot-tying skill.

Barthol and Ku (1953) studied regression, moving backwards in a situation, under non-related stress situations. These authors suggested that frustration, fatigue, and conflict are stressful and that under stressful conditions an organism will respond to stress using the first behavior learned appropriate to the situation. They tested the hypothesis that under stressful conditions after learning two behaviors appropriate to a particular situation, the behavior learned first would be the individual's response. Participants were taught two ways to tie a bowline knot. Next, they were placed in a stressful situation (taking a difficult intelligence test they were told was easy). The hypothesis was supported: Eight out of 10 participants tied the knot the way they were first taught. One simple implication of this study is that there are different ways of tying knots; learning to tie knots on one's own may require exploring multiple strategies to complete the knot, suggesting improvement over trials.

Zuckerman (1915) studied the most effective medium for teaching people from an instructional film. The amount of commentary, personal reference of the commentator, and how well the sound worked with the film were evaluated by having participants watch the instructional film and then perform tasks such as shoe-tying. Results showed that a moderate amount of commentary improved learning but too much talking took away from learning. When the commentator used the imperative mood, learning was positively influenced. Having the sound slightly ahead of the film helped participants more than sound that was slower than the film. This finding suggests again that variations in training procedures influence learning, but also suggests that perceptual elements are important to knot tying tasks.

Cooper (1969) taught pre-school children skills to help them perform in the academic world and to become more independent behaviorally. Skills like tying their shoe laces were taught by simplifying the steps to complete the tasks, isolating correct behaviors, and using reinforcement for correct responses. This training enabled faster behavioral development of the children. As children are taught and respond correctly, they do the task faster and more accurately. Cooper's results suggest that feedback on tying knots correctly positively influences learning.

The literature shows studies attempting to teach life skills, focusing on making life easier for those who have difficulty with common tasks. Others focused on feedback and situational variables. Psychological processes involved with tying knots were examined very little. Knot-tying was used as an example task, but not examined in itself.

In general, the point of the present work was to explore how people go about learning to tie knots. More specifically, are there more limited categories of psychological functioning that are particularly important to such learning?

One could summarize from the uses of knots in other studies that knot tying can be classified as a perceptual-motor skill. It follows that learning to tie a specific knot requires individuals to pick up perceptual information about the pattern of rope crossings (over and under) unique to that knot. Either while learning the perceptual skills or afterwards, the motor skills to manipulate rope to produce that knot have to be learned.

Gibson (1969) defines perceptual learning as increased ability to see differences among objects or patterns. This process of learning to discriminate among similar objects or patterns is termed differentiation, and this process occurs as observers have the chance to study and compare patterns. Gibson and Gibson (1955) demonstrated this process by setting up an example. Observers viewed a series of scribbles, which were spiral patterns that varied in their number of twists, left-right orientation, and compactness. With practice observers steadily improved their ability to judge whether scribbles were the same as a standard scribble or not.

Learning to tie a knot should involve the same kind of differentiation, the ability to tell that one pattern of strand crossings is correct while other patterns of strand crossings are incorrect. The correct strand crossing pattern is the target knot. In the demonstration of differentiation, Gibson and Gibson (1955) gave observers feedback or knowledge of results (KOR). Gibson (1969) suggests that feedback is not essential for differentiation to develop; simple exposure to observed patterns under conditions that allow the patterns to be compared is enough. However, if feedback is given, perhaps observers can learn quicker by focusing their attention on specific details of the object.

Development of the present study revolved around three key points. Knot tying is a behavior that has been around for a very long time, but the patterns of behavior that allow for knot tying have not been studied. There are many practical applications of knot-tying skill such as medicine, biology, and recreational uses for knots. The problem of how people go about learning to tie knots clearly has psychological dimensions. A theoretical view of the problem involves differentiation theory's overall focus. The primary theme of the present study then is how perceptual differentiation training influences knot tying, as suggested by both theoretical and empirical literature.

Experiment 1

The available literature gives little guidance about what behaviors are most important in learning to tie knots, so an initial observational study was designed to collect a sample of behaviors that occur while individuals are tying knots. The experiment was cast as a learning task. Participants were asked to tie four knots increasing in complexity, where complexity was judged by how difficult it appeared to be to trace the patterns of strand crossings in each knot.

There were two goals of the study. One was to look at improvement in knot tying ability across trials, measured by time to tie the target knot. The second goal was to look at the behavior patterns of the participants. Those behaviors that occurred consistently among many of the participants were behaviors that might be used in subsequent studies. Behavior patterns that supported the expected influence of perceptual ability were, of course, of special interest.

Method

Participants

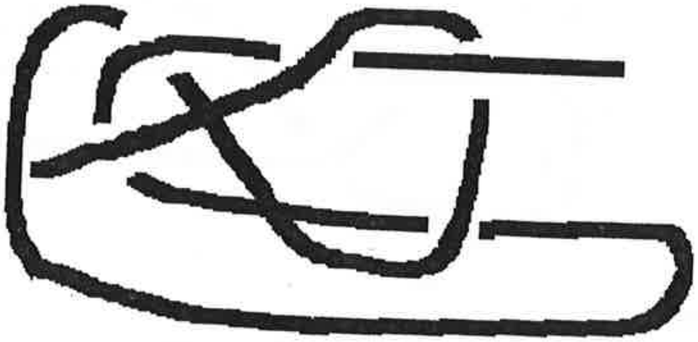
Eleven Pembroke State University students (9 female, 2 male) participated. All were given credit for participating in the study in various classes of the psychology department. All participants were between the ages of 18 and 20 years. Of the 11 participants who attempted the experiment, three did not complete the test sessions. All stated reasons of frustration and that they did not possess the skills to complete the knot-tying, and so chose to withdraw from participation. Those volunteers' data on knot tying trials was not analyzed, but they were included when reporting about behavior. None of the participants reported any formal knot-tying training. All signed an informed consent form at the beginning of the test session giving permission to videotape them as they worked. Participants were given a debriefing after the experiment to explain the study.

Apparatus

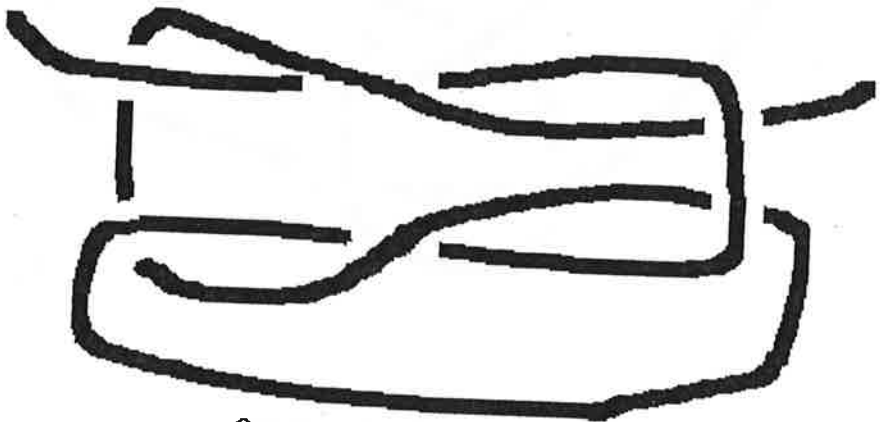
Materials used included four target knots judged to be of increasing complexity as models for the participants to compare their attempts with (Figure 2). A figure 8 knot, a square knot, a sheetbend knot, and a bowline knot were tied using rope 1.2 cm thick and 76.2 cm in length. Each of the four knots was mounted on a separate 27.5 cm by 27.5 cm square piece of 0.64 cm thick plywood, painted light blue. Participants used two ropes of the same specifications as those used to make the knot models to tie knots with. A stopwatch was used to time each attempt at tying each knot. A video camera, mounted on a tripod across the table from the participants, was positioned so it was focused on their hands and upper bodies.

Procedure and Design

Before entering the room, observers were asked to sign the informed consent agreement. The video camera was turned on as the participant entered the room. The participant was seated at the table and told that their task was to tie four different knots correctly. They had a 5 min maximum time for each trial per knot: they had five opportunities to tie the knot correctly. The knot judged easiest, the figure 8, was presented to the participant first and he or she was given a piece of rope to tie a replica of the model. Each trial started as soon as each model and rope was handed to the participants. The stopwatch was started as materials were handed to the participants. Trials ended (the timing was stopped) when the participant stated that they were finished tying the knot. After five trials with that knot, the participant was given the square knot



Sheetbend Knot



Square Knot

Figure 2. Knots used in Experiment 1

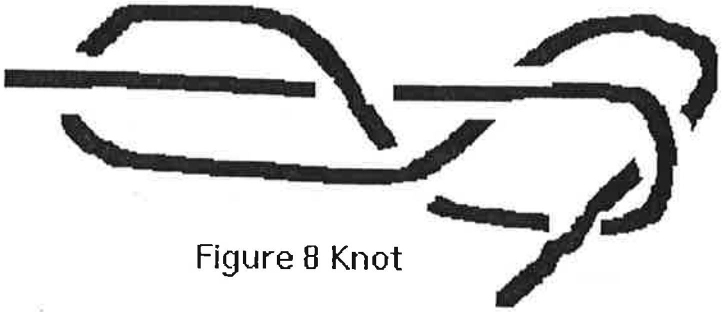


Figure 8 Knot

Bowline Knot

Figure 2. Knots in Experiment 1 (cont.)

to try and replicate. Next the sheetbend knot was given to the participant to tie. The last knot presented was the bowline knot. All participants tied the knots in the same order.

After the knot-tying trials were complete, each participant was asked about knot-tying experience and childhood memories about tying their shoelaces.

Results

Learning trials

Times for each trial for each participant were entered into a 4 (knots) x 5 (trials) analysis of variance. Results showed that times improved across trials, $\underline{F}$ (4, 140) = 6.681, $\underline{p}$ <.001, and that the times for each target knot differed significantly, $\underline{F}$ (3, 140) = 5.013, $\underline{p}$ <.01. The interaction was not significant ($\underline{F}$ <1.00). So, participants improved with practice on all knots, but some knots were more difficult to learn to tie. Mean times to tie each knot in each trial are shown in Figure 3. The statistics showed over the five trials the time it took to tie each knot decreased. As the knots grow more complex, the time taken to tie each knot is increased.

Behavioral observations

Participants showed several relatively common patterns of behavior as they attempted to tie the knots. Generally, each participant spent quite some time studying each knot model before any attempt was made to tie a knot. Tracing the models with their fingers was a common behavior pattern among participants, suggesting they were attempting to become familiar with the strand crossing pattern of the knot. Most participants laid the rope to be tied flat on the table, beside the model so the two could be compared. These observations suggested that an initial step in learning to tie a given knot was to differentiate perceptually the patterns of strand crossings for that knot.

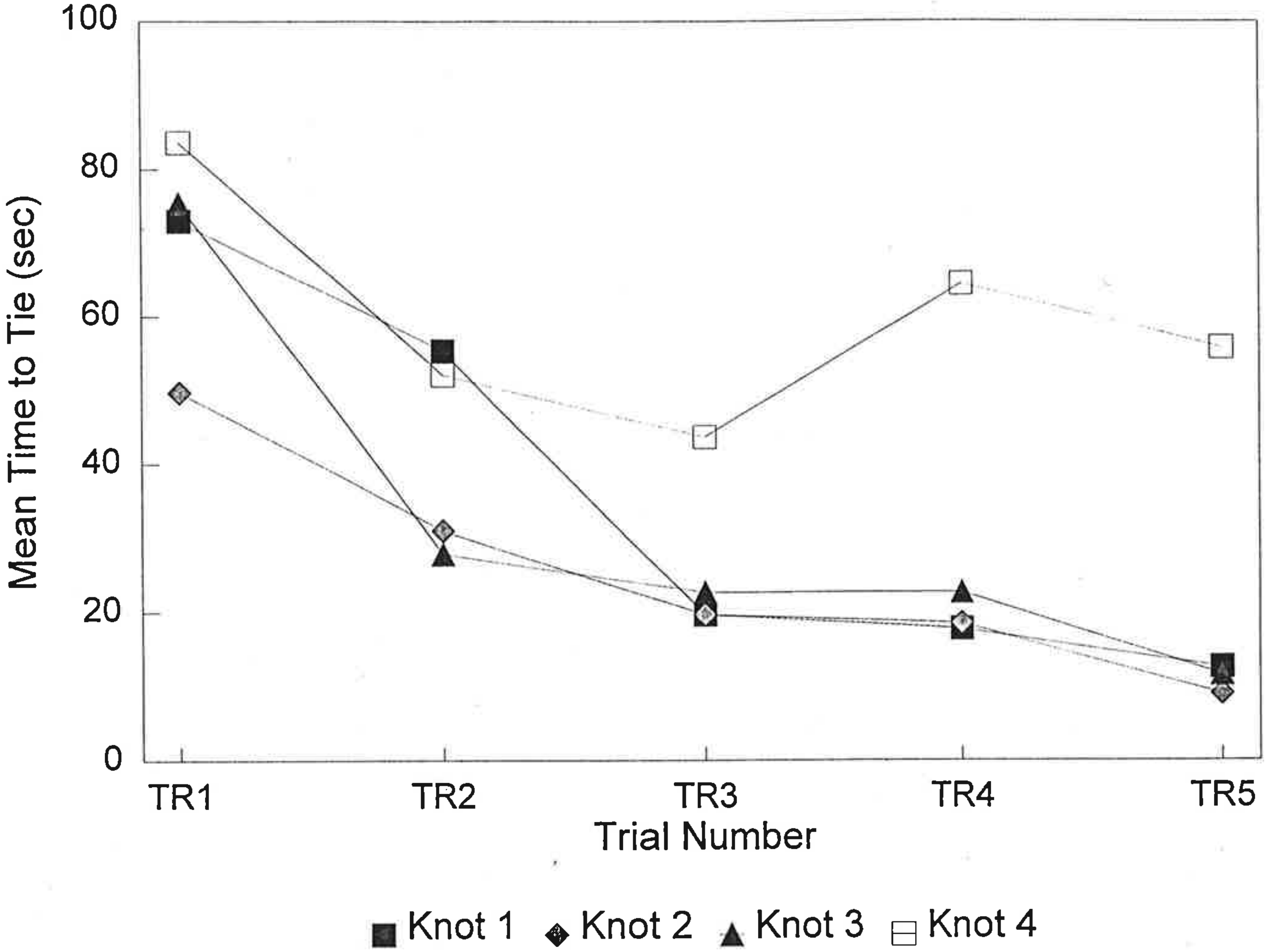


Figure 3. Mean times to tie each knot in each trial of Experiment 1

Some other patterns also suggested perceptual learning as important. Several other participants talked out loud to themselves so they could remember the mistakes and successes they were having. Participants seemed to either focus on the knot as a whole to try and figure out how to tie it or focus on one end of the rope and follow it through the knot. A few participants held the rope to be tied up in the air instead of laying it on the table. These individuals seemed to wrap the rope around itself, following the model closely instead of tying the knot using trial and error.

I noticed that six of the participants used a very systematic way to solve how each knot was tied. Those six tied the same pattern over and over looking at the model and adjusting their ropes until what they had tied matched the model. Those who focused on one end of the rope towards the outside of the knot and followed it through the middle of the knot seemed to figure out the knots faster than those participants who looked directly at the middle of the knot and tried to tie the knot manipulating both ends of the rope.

The three participants who withdrew showed no recognition of the knot having a starting point or an ending. All used more or less random trial and error to tie each knot. None could apparently tell the difference between the model knot and the incorrect knot they had tied, and tended to repeat the same errors from trial to trial. These elements again suggested that the perceptual ability to differentiate knot patterns was important to knot-tying success. In no case did it appear that participants had any special difficulty with the motor skill involved with manipulating the rope. The problem was not managing the material, but seeing and remembering the knot pattern.

Discussion

The eight participants who completed the study clearly learned to tie the target knots, though all participants appeared to have some initial problems completing the knots. Many commented that the task was difficult and tedious. Participants appeared nervous about being taped while they worked, particularly early in the session.. One participant expressed confusion between knots when trying to tie each, even when the model of the knot the participant was working on was there on the table to compare with. This study gives clear evidence that college students are not very skillful at tying knots and they get better (faster) with repetition.

This finding is supported by all the literature that examined training participants to perform perceptual skills like knot-tying. Zuckerman (1915), Biederman and et al. (1991), and Barthol and Ku (1953) all showed that with practice participants become more skilled at tying knots.

There were regularities in the patterns of behavior seen as participants learned to tie the knots. These behaviors occurred while many of the participants were observed. The regularities suggested that perceptual learning was an important influence in learning to tie knots.

There were a number of limitations on the results of the experiment. The main aim of this study was to observe knot-tying behavior as individuals learn to tie knots. The statistical outcome is useful to show that learning occurs, rather than to make any firm statements about how learning actually occurs. There was no special attempt to focus on perceptual learning and no effort to guide attempts to tie the target knot using feedback. No instructional time was spent on how to tie the knots. Other kinds of knots also might have produced different patterns of performance and behaviors.

The small number of participants limits any attempt at generalization of these results. While a reasonable degree of consistency in both knot-tying performance and in patterns of behavior were seen, it is possible that greater ranges of skill and patterns of behavior might have been observed with a larger sample.

The statistical results showed a general decrease in time to tie across trials. But, it is likely that ability to tie knots presented later in the test session benefited from practice on knots presented earlier. Even so, the knots were presented in order of increasing judged difficulty. The results suggested that later knots were more difficult to tie (longer times per trial on average) even with the earlier practice on presumably easier knots. However, difficulty and order were completely confounded in this study, so no clear conclusions about the influence of knot difficulty can be drawn.

No attempt was made to note errors in knots tied. The assumption was that participants could see when the knots they tied did not match the model, and would correct their errors until they did get a match. Very often this is just what happened, but on some trials the participant ended the trial with a knot that did not match the model. Consequently, though times per trial generally reflect correct attempts, a few of the trials included in the data are for knots that would be scored as errors.

The patterns of behavior observed suggested the influences of perceptual differentiation of strand crossing patterns before actual attempts to tie the knots occurred. Differentiation and KOR seem to be important aspects of learning to tie knots. These two variables were the focus of Experiment 2.

Experiment 2

Experiment 1 suggested that psychological processes involved in learning to tie knots are at least in part perceptual. The Gibson and Gibson's (1955) theory related to this component showed that the skill of differentiating patterns of target stimuli was important in learning. Studying the patterns of behavior seen in Experiment 1 was consistent with this view. When participants tied the knots they frequently compared their developing knot with the model. In many cases the participants stopped trying to tie each knot and just studied the models. Those who studied the models appeared to learn to tie the knots more readily than those who did not compare their knots with the models. From observing participants while they were attempting to tie the knots, those who apparently recognized that the way strand crossings were manipulated affected whether they tied the correct knot performed better than those participants who did not apparently realize there was a pattern involved.

Logically, then it seemed useful to study the possible effects of differentiating knot patterns on the ability to tie knots. Since knowledge of results (KOR) is known to be helpful in promoting learning in other situations (Cooper, 1969), and since some participants made mistakes monitoring their own performance in Experiment 1, KOR was also tested as a variable possibility influencing ability to learn to tie knots. In order to limit the number of patterns was limited in differentiation testing, a single knot, a square knot, was used. Further, it was apparent in Experiment 1 that even this relatively simple knot was difficult (or impossible) to tie for some participants.

Several hypotheses were tested: the differentiation of knot patterns would occur if the opportunity for participants to study patterns and pick out the target knot occurred.

Increasing ability to discern patterns and pick the target knot would be measured by increased speed in making each judgment. Learning would occur as participants tried to tie the square knot. Learning would be measured by increased speed on knot tying trials. Participants who got differentiation training would learn to tie the knots more readily than those who did not get differentiation, as measured by faster speeds per trial and the number of trials to a learning criterion. Participants who received knowledge of results after each knot tying trial would learn faster than those who did not receive it, as seen in times to tie and in trials to criterion.

Methods

Experimental Design

The experimental design showed the following independent variable combinations: differentiation experience with KOR, differentiation experience without KOR, non-differentiation experience (articles to read) with KOR, and non-differentiation experience without KOR. Trials (or blocks of trials) was an additional variable in some analyses. The statistical designs were 2 (differentiation experience or not) x 2 (KOR or not) x trials or trial blocks (3 to 6, depending on the dependent variable used).

Participants

Forty three volunteers participated in the study. Twenty-six subjects were attending college at Pembroke State University. Three subjects were attending school elsewhere. All other volunteers were friends with college degrees. Participants were between the ages of 18 and 51 years. The median age was 22 years. There were 26 women volunteers, and 17 men. Of those who volunteered, eight reported some formal training in knot tying (defined as a class or training with similar structure); all participants received such training while in military service. Participants who requested it were given credit for their participation in various psychology classes. All signed an informed consent agreement before participating. All participants were given a detailed debriefing of how the experiment was being conducted and what the rationale was for the study.

Of the volunteers, three did not complete the test session and were dropped from the analysis. The three participants who did not complete the test session, did not because of their failure to meet the learning criterion (tie three consecutive correct square knots). All gave up before accomplishing the task. When asked why they could not finish the task, all three reported feelings of frustration and that they did not have the patience or know-how to tie the knots.

Apparatus and Materials

Differentiation experiences. Materials used included a binder with 126 photocopied drawings based on a square knot pattern. Half of the patterns were correct and half incorrect square knots. An incorrect square knot was identified by the crossovers of each knot. Each knot has six crossovers which were numbered 1-6 (see Figure 4). The designation of the ropes as over or under in the crossover was accomplished by assigning each numbered crossover "A" or "B" based on whether the crossover had the more horizontal piece of rope cross over or under the vertical rope. A truth table was set up to calculate every possible combination of crossovers. Within the truth table there were 64 possible patterns of crossovers, only one of which was a correct square knot. Thus, 63 incorrect (i.e., non-square knot) patterns were systematically constructed. Each crossover was painted using white out to cover whatever rope in each

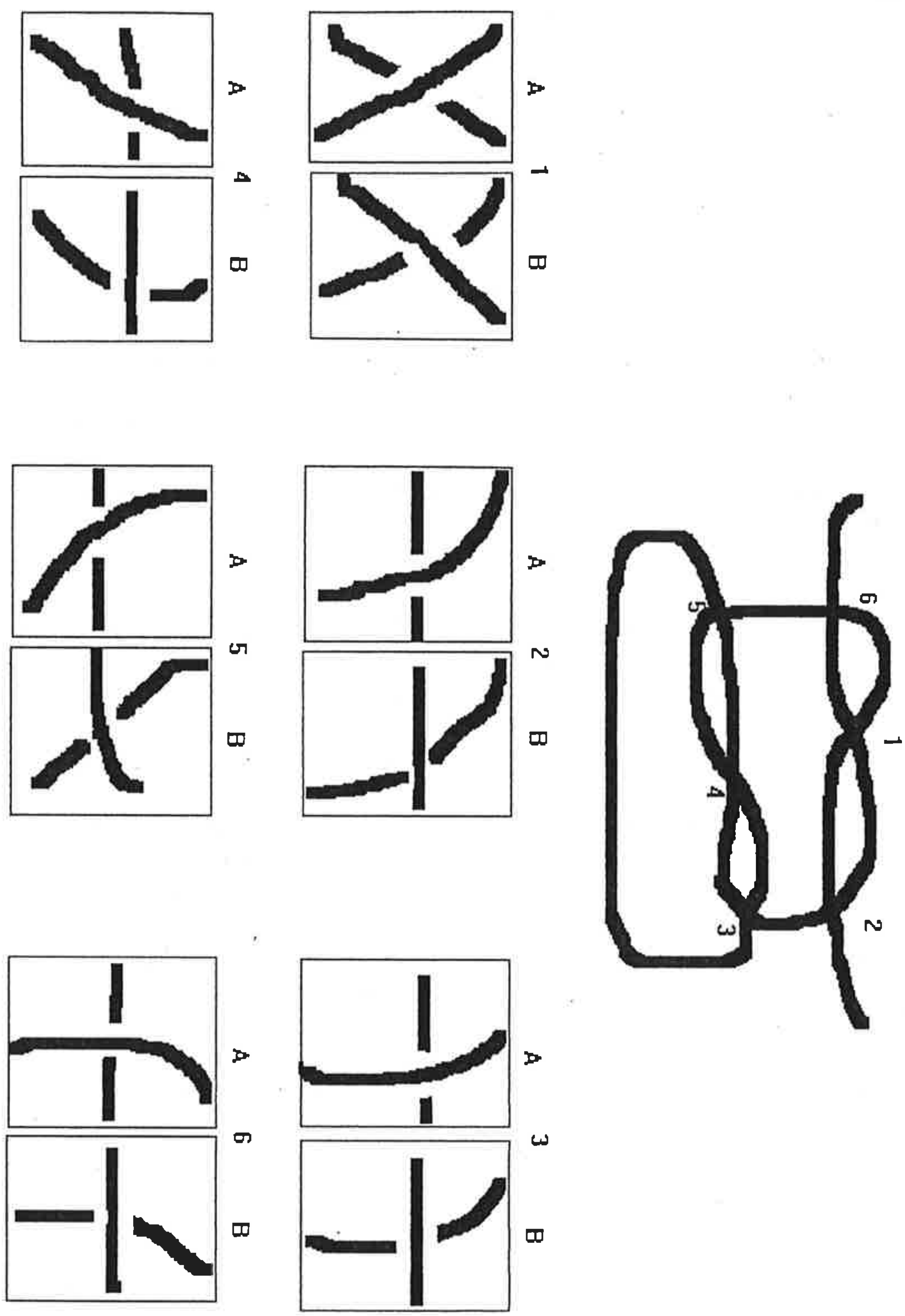


Figure 4. The six crossovers of a square knot

crossover was to appear as under the other rope (see Figure 5). The drawings were shuffled and placed in the binder with the restriction that no more than three incorrect or correct patterns occur in a row.

A single sheet with a correct square knot on it was used by participants to make comparisons with the knots in the binder.

In an attempt to make sure all session times were roughly equal for participants who did and did not receive differentiation experience, non-differentiation participants read parts of three articles about knots in general. The segments were taken from Berreteaga (1991), "Strands of" (1994), and Cipra (1992). Each article was limited so they were all one page apiece. All articles were mounted on heavy, red construction paper for ease of handling. These articles were used in the independent variable groups that received no differentiation experience so all groups would take the same amount of time in completing the test session.

Knot-tying trials. A piece of rope, 94 cm long and 0.64 cm wide, was used for tying the actual knots. Another rope of the same size was made into a square knot for participants to have as a model. In contrast to Experiment 1, the model was not glued to a panel so participants could look at it from any perspective.

Procedure

The goal of each test session was for the participant to get differentiation training or not depending on their group assignment. Each participant was then asked to tie a square knot using the model as an example. Each attempt was timed. The session was complete when the participant tied three square knots correctly in a row. Participants were placed in one of the four experimental groups based in the order that they came to

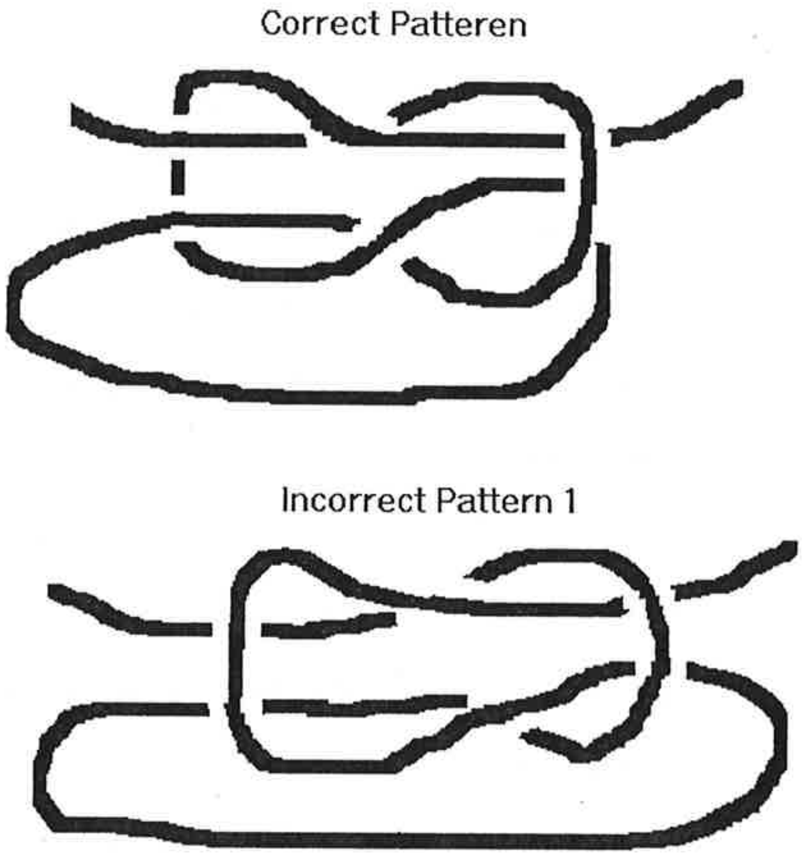


Figure 5. Possible square knot patterns

participate in the study. Individuals in Group 1 received both differentiation training and KOR on the correctness of their knot-tying attempts. Individuals in Group 2 received differentiation training without KOR. Individuals in Group 3 read articles and received KOR. Individuals in Group 4 read articles and got no KOR.

Differentiation experience. Participants identified whether or not each of the 126 representations of strand crossings was the same as or different from the model picture by saying out loud "same" or "different". The total set was divided into six blocks of 20 judgments (with the last trial having 26 judgments). Each block was timed. Responses were recorded on an answer sheet by the experimenter as the participant called out their answer.

Those who were in Groups 3 and 4 read the three articles discussed in the Materials section. They were not timed while reading. The differentiation training and the article reading took approximately 20 min apiece.

Knot-tying trials. All participants were asked to attempt to tie a series of square knots. A rope knotted into a square knot was used as a model for the participants to compare their work with while working with another rope. The participant was free to pick up the model, perhaps trace it with a finger, and examine it from multiple perspectives. The criterion for learning was for the participant to complete tying a square knot three times in a row correctly. Each attempt at tying a square knot was timed. Individuals in groups given KOR were told whether or not the knots were correctly tied upon the participant reporting the knot completed. Those without KOR were not told whether or not their knots were correct. They were simply asked to tie another knot until they got three knots tied correctly consecutively or indicated that they wanted to stop the experiment. Each test session took about 30 min.

Debriefing. After the knot-tying trials were complete, each participant was asked if they had any previous knot-tying experience. The extent of training was questioned if the participants indicated prior training. Childhood memories concerning learning to tie shoelace knots were also asked about. These questions were asked to see if some pattern could be found in the behaviors observed during the experiment and define the extent of each subjects' experience. Finally, each participant was told the rationale of the study, what group that particular participant was part of, and how that was used in combination with the other groups in the study.

Results

Differentiation experience

Times for differentiation trial blocks were converted to mean time per trial within each block (see Figure 6). Those mean times were compared for the KOR and non-KOR groups across the six trial blocks in a 2 x 6 analysis of variance. ANOVA showed that there was a significant main effect for trial blocks, $F(5, 90) = 8.897$, $p < .001$. The main effect for knowledge of results was not significant, $F(1, 18) = 1.189$, $p = .290$, nor was the interaction of KOR and trials, $F < 1.00$. So, times to judge correctness of patterns improved across blocks, and the two KOR/no KOR groups were equally good at the task, before knot-tying trials.

Knot-tying trials

Mean times to tie the square knot correctly on the three criterion trials were calculated from individual data sheets (see Figure 7). Times to tie the square knot

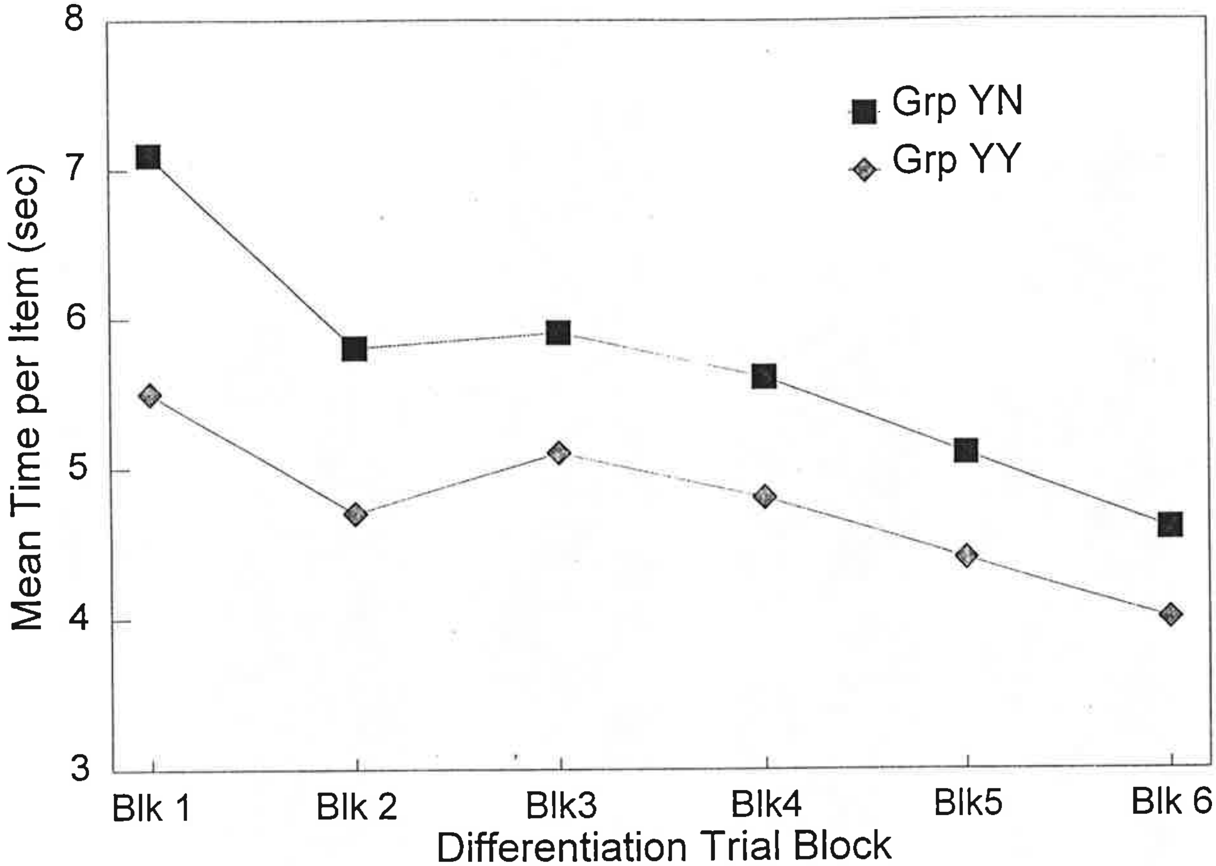


Figure 6. Times for differentiation trial blocks

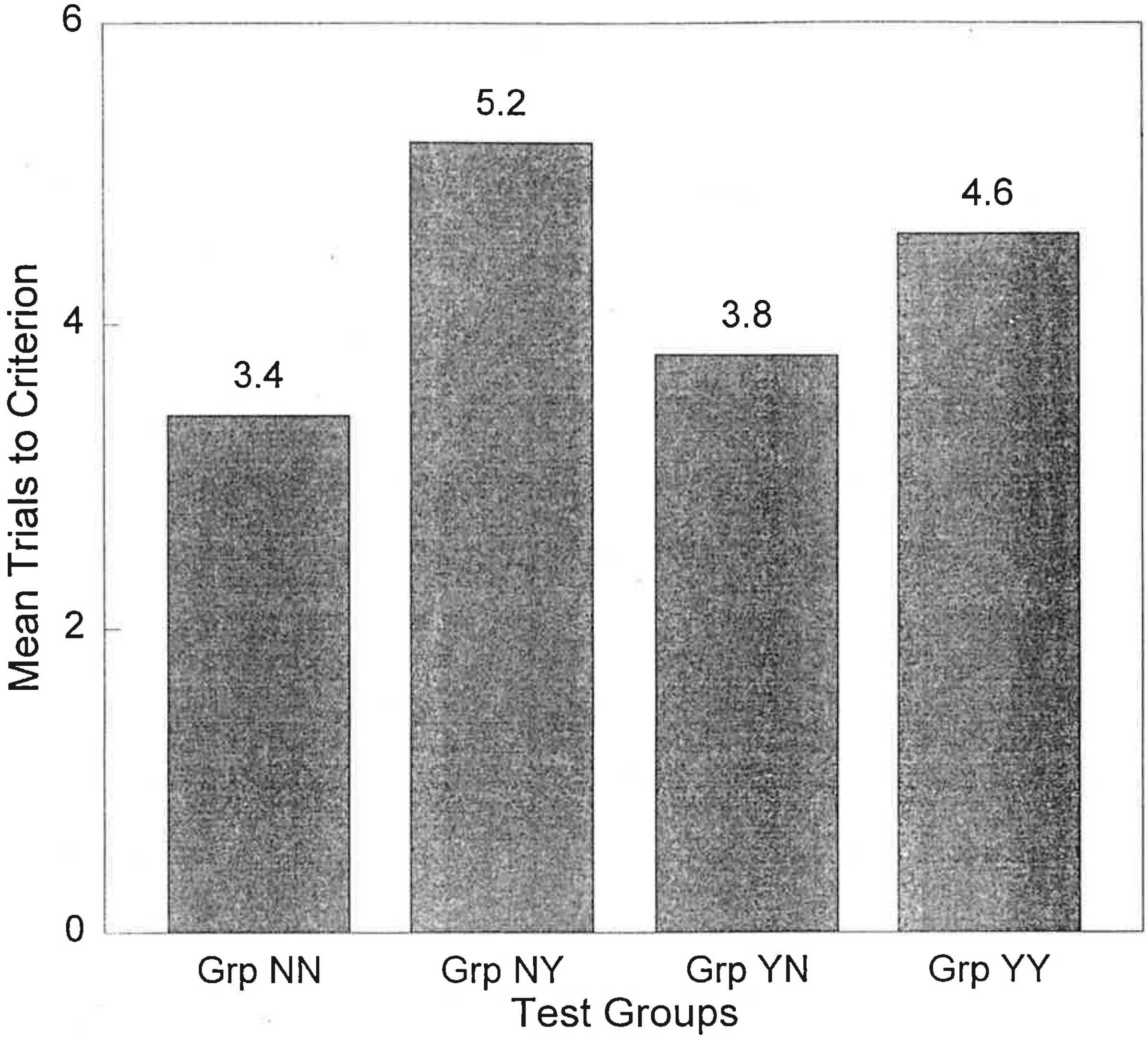


Figure 7. Mean times to tie correctly on criterion trials

correctly were compared in a 2 (differentiation vs. no differentiation) x 2 (KOR vs. no KOR) x 3 (trials) ANOVA. The ANOVA showed significant main effects for trials $\underline{F}$ (2, 72) = 6.106, $\underline{p}$ = .004. The interaction of trials and differentiation was not significant, $\underline{F}$ < 1.00. The main effect for KOR was not significant, $\underline{F}$ < 1.00. The interaction of trials and KOR was significant, $\underline{F}$ (2, 72) = 3.464, $\underline{p}$ = .037. The main effect for differentiation was not significant, $\underline{F}$ (1, 36) = .214, $\underline{p}$ > .647. The interaction of differentiation and KOR was not significant, $\underline{F}$ < 1.00. The three-way interaction of KOR, differentiation, and trials was not significant, $\underline{F}$ (2, 72) = 1.491, $\underline{p}$ =.232. These results showed that with practice, participants got better at tying knots and that differentiation and KOR had little influence on the improvement of knot-tying skills (see Figure 8).

Repeating the analysis without the data from individuals who reported prior knot-tying experiences did not alter the pattern of results. The trials main effect was again significant, $\underline{F}$ (2, 50) = 3.819, $\underline{p}$ = .029. The differentiation and KOR main effects were not significant, both $\underline{F}$ < 1.00. The interaction of trials and KOR was still significant, $\underline{F}$ (2, 50) = 3.806, $\underline{p}$ = .029 as it had been with the experienced participants included. The trials x differentiation and trials x differentiation x KOR interactions were not significant $\underline{F}$ < 1.00 and $\underline{F}$ (2, 50) = 1.220, $\underline{p}$ = .304 These outcomes suggest that past experience was not especially helpful in this task.

Trials to criterion were compared in a 2 (differentiation vs. no differentiation) x 2 (KOR vs. no KOR) ANOVA. Neither of the main effects were significant: Differentiation, $\underline{F}$ < 1.00; KOR, $\underline{F}$ (1, 36) = 2.836, $\underline{p}$ = .101. The interaction was also

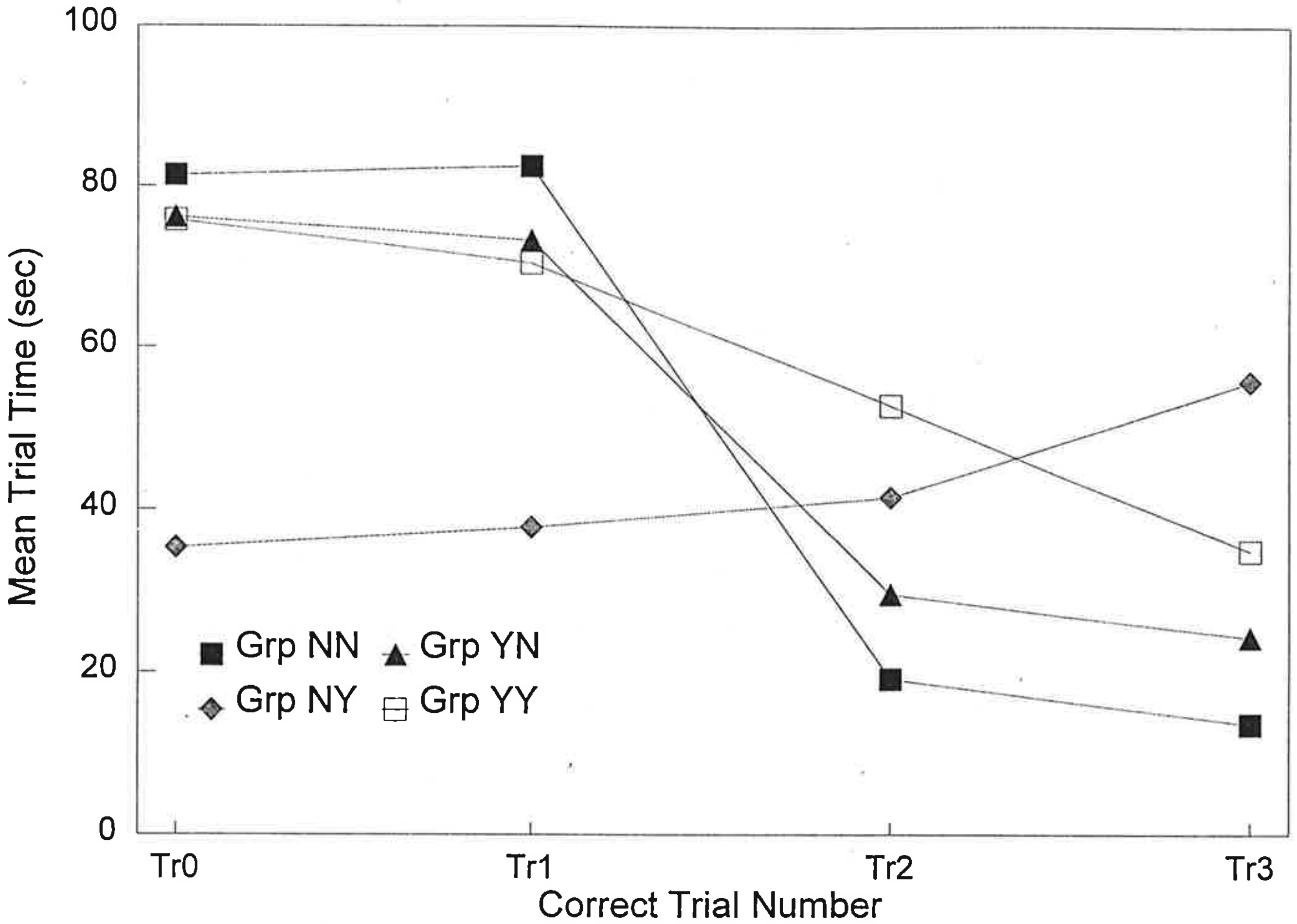


Figure 8. Results of Experiment 2

non-significant, F < 1.00. So, even though knot-tying speed differed, the number of attempts needed to reach criterion was about the same under all test conditions.

Discussion

As individuals practice tying knots, they get better and faster. Differentiation occurred as predicted. Trials to criterion did not differ among the experimental groups. Exposure to square knot patterns improved participants recognition of the target pattern. Learning was seen in the knot-tying trials as predicted. A decrease in the time it took to tie each knot with practice was evident. Neither KOR or differentiation experience improved learning to tie the square knot, whether participants reported past knot-tying experience or not.

Again these findings are supported by literature that examined training participants to perform perceptual skills like knot-tying. Zuckerman (1915), Biederman and et al. (1991), and Barthol and Ku (1953) all showed that with practice participants become more skilled at tying knots.

Participants looked at me often for physical reinforcement; for example, leaning forward, nodding my head, smiling. Based on what was observed during test sessions, participants who received KOR seemed more confident of their skills. They also seemed more creative in their solutions to complete each knot. Participants who received no feedback seemed to have had to try harder to compensate for the experimenter being uninformative. They seemed to more unsure of their skills and hesitant to try new approaches to solving how to tie the knot. Those who received no KOR seemed to get discouraged more readily and give up more easily than those who were told if their attempts were correct or not.

This finding is supported by the research of Cooper (1969) and of Barthol and Ku (1953). Both suggested that reinforcement for knot-tying positively influences learning.

Gibson and Gibson (1955) had success with participants being able to differentiate between patterns in different presentations; however, all presentations used the same medium. It was curious that although subjects got better at discriminating between knot-like patterns within the differentiation training blocks, they were unable to generalize that differentiation to actually tying a physical square knot. During the knot-tying trials, many tied incorrect knots similar to square knots. Apparently participants could not see the difference between the target knot and an incorrect knot even with the rope model in front of them. However, they could make the determination between an incorrect and a correct square knot on paper.

One limitation of this experiment involved participants. With a limited volunteer population to draw a sample from, several participants had prior experience with knot tying that may have allowed them to apply the skills they learned in the past to the knot they were asked to tie in this study, although this did not yield a statistical difference.

Differentiation training and feedback were the two variables that were studied as possible influences on knot-tying skill. A second limitation to this study is that there are possibly other factors that may influence learning knot-tying skill. Interaction of these factors with the variables studied here could make a difference as to whether they would be positive influences on learning.

General Discussion

The results of the two studies show that with practice participants get better and faster at learning to tie knots. Within differentiation training, participants got better at discriminating between the target knot and incorrect patterns. However, those who received differentiation training did not learn any faster than those participants who read articles. KOR did not have any influence on how quickly individuals learned to tie knots.

Some results found were not consistent with the literature reviewed during this study. Barthol and Ku (1953) and Cooper (1969) both suggested that KOR positively influences learning. However, in this study it did not seem effective when used as a positive influence on knot-tying skill.

This study showed the same results as the literature which examined teaching life-skills (Biederman, et al.; Cooper, 1969; Moreno, 1991; Zuckerman, 1915). With practice participants become better and faster at the target task.

The results of these two studies show consistent behavior patterns. In particular, there were two behaviors that occurred frequently while watching the videos in Experiment 1 and in review of the notes in Experiment 2. One was the way people held the rope when tying the knot. A few subjects held the knot in the air, so it would be more 3-dimensional. The rest of the subjects laid the rope flat on the table only lifting the rope enough to wind it into a knot. By observation, it seemed that those who held the rope up in the air spent less time on studying the problem than those who laid the rope flat on the table, and seemed to learn to tie the knot faster. A question for future research, then is the effect on knot-tying of restrictions on how the rope is manipulated..

The second behavior noted was the way subjects attacked the problem of tying the knot. Almost all subjects started tying the knot by tracing the knot from one end of the rope, focusing on figuring out the middle. It was interesting to watch the three participants who approached the problem from the outskirts of the knot, taking one end and wrapping it around the other end to create a middle because so few attempted that as a solution to the problem. Why did those participants approach the problem so differently from all others tested? All participants seemed to fall into two categories: those who looked at the model carefully and traced it with their eyes or fingers and those who jumped right into solving how to tie the knot. Those who took no time to think about a logical way to approach the problem seemed to take longer in tying the knot than subjects who examined the model first.

It seems with both behaviors that an important part of learning knot-tying is allowing the mind to rationalize and form a solid understanding of how the knot is made up. Participants constantly comparing their rope with the model suggests that acquiring a concept of knot beginning and end is essential for knot-tying success.

From observations in both experiments, I conclude that participants that had previous exposure to knot-tying even if it was not the same knot used in my study, do not perform than those than those who report no prior training. It is possible that this type of procedural memory just is not as persistent as other kinds of memories. But, clearly some procedural memories last a long time (such as swimming or riding a bicycle). So perhaps knot-tying is an odd kind of skill. On the other hand, maybe the particular task here (tying a square knot) is just easy enough for non-experienced participants that they do not look different from experienced ones.

This raises the questions of varying the difficulty of knots and of testing memory for knot-tying over time, both possibilities for future research. A possible continuation of research could also include looking at whether participants tested in the original study remembered the square knot in the following year. Would discrimination training and knowledge of results influence remembering the knot over time?

Observations of the present study and research examined in the literature (Barthol and Ku, 1953) showed that stress and frustration may have a large influence on how well people learn knot-tying skills. As people experience problems while learning to tie knots, it appears they become aggravated because they can not solve how to tie the knot. A good possibility for future research would be to look specifically at how the influences of frustration and stress affect learning to tie knots.

One limitation of the study was that only KOR and differentiation training were looked at. The studies reviewed in the literature examined other variables. Perhaps, the present study should have looked at things like presentation of instructions (Zuckerman, 1915) or whether passive or interactive learning would be more conducive to learning to tie knots (Biederman, et al., 1991).

This study could be a step in further research towards the question of how people go about tying knots because it at least found that differentiation and KOR have very little effect on the skill of learning to tie knots, under the conditions used. Many of the questions I attempted to answer in my study just turned up more questions. Another research question could attack discrimination training using stimuli that would be presented in much similar ways than the previous study. Future research should examine other variables that may influence knot-tying. Perhaps in other variables lie the missing piece to the puzzle of how people learn to tie knots.

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