In Depth Study Permission and License

By signing and submitting this agreement, I grant Olds College the non-exclusive license to archive and make accessible my Master Spinner Program In Depth Study in whole or in part in all forms of media now or hereafter known for educational, research, and scientific nonprofit uses during the full term of copyright. I retain all other ownership rights to the copyright including the right to use in future works (such as articles or books) all or part of my work.

I represent that the submission is my original work, and that I have the right to grant rights contained in this license. I also represent that my submission does not, to the best of my knowledge, infringe on anyone's copyright and that I have obtained written permission from the owner(s) of any third party copyrighted matter included in the work.

I understand that my In Depth Study will be placed in the Olds College’s library for access to the public. I will understand that I will clearly be identified by name as the author of the submitted work and that Olds College will not make any alteration other than as allowed by this license to my submission.

Signed: ________________________________  
Date: July 11, 2019
Elasticity and Resiliency in Handspun Yarns

Stetson Weddle

Submitted to Olds College

December 5, 2018
Abstract

Today's handspininers have a handful of useful terms to describe and document their handspun yarns. Twists per inch (TPI), angle of twist (AOT), and wraps per inch (WPI) are now fairly well understood by all levels of handspininers. Although elasticity and resiliency are part of the common lexicon, elasticity is only used in the general sense, and resiliency appears rarely in descriptive terms about handspun yarns. Nevertheless, elasticity and resiliency are important factors in determining and predicting the behaviour of the ultimate application for handspun yarns, namely knitted and woven garments. This study focuses on a quantitative analysis of the elasticity and resiliency of yarns where the constituent fibres are non-elastic blended with elastic fibres. Finally, the study presents a new quantitative method of describing handspun yarns in combined terms of elasticity and resiliency: liveliness.
Table of Contents

Abstract .......................................................................................................................... 2
Introduction .................................................................................................................... 6
Elasticity, Resiliency and Liveliness .............................................................................. 9
  Parameters ................................................................................................................... 9
  Equipment .................................................................................................................. 13
Fibre Preparation .......................................................................................................... 15
  Fibre Selection .......................................................................................................... 15
  Fibre Preparation ...................................................................................................... 16
  Spinning Method ....................................................................................................... 19
  Finishing Method ...................................................................................................... 22
  Measuring Technique ............................................................................................... 22
  The Findings .............................................................................................................. 27
  Observations .............................................................................................................. 28
Results .......................................................................................................................... 29
Conclusions .................................................................................................................... 35
References ...................................................................................................................... 40
Appendix A ..................................................................................................................... 41
  Areas for Further Study ............................................................................................ 41
Appendix B ..................................................................................................................... 43
  Example of Raw Yarn Data ...................................................................................... 43
Appendix C ..................................................................................................................... 44
  Partial Catalog of Equipment .................................................................................... 44
Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Stress Strain Curve (Hussain, 2012)</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Cormo Locks</td>
<td>17</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Alpaca/Merino Premix</td>
<td>19</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Third Pass of Carding</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Continuous Worsted Technique</td>
<td>21</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Source Fibre Elasticity Test</td>
<td>23</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Yarn irregularity</td>
<td>24</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Weighted Elasticity Test</td>
<td>25</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Woven Sample Test</td>
<td>26</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Knitted Sample Test</td>
<td>26</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Alpaca Skeins</td>
<td>28</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Silk Skeins</td>
<td>29</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Elasticity Gain (Weighted)</td>
<td>30</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Elasticity Gain (Hand-stretched)</td>
<td>31</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Resiliency (Weighted)</td>
<td>31</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Elasticity Gain Alpaca Yarn and Knitted Garment</td>
<td>33</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Elasticity Gain Silk Yarn and Knitted Garment</td>
<td>33</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Elasticity Gain Alpaca Yarn and Woven Garment</td>
<td>34</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Elasticity Gain Silk Yarn and Woven Garment</td>
<td>34</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Liveliness Graph</td>
<td>36</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Liveliness Calculator Website</td>
<td>39</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Stress and Measuring Equipment</td>
<td>44</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Patrick Green Supercard (Unknown, Supercard)</td>
<td>45</td>
</tr>
</tbody>
</table>
Table of Tables

Table 1 - Alpaca Sample Groups ................................................................. 17
Table 2 – Tussah Silk Sample Groups .......................................................... 18
Table 3 - Liveliness Index 2-ply Sample Yarns ........................................... 37
Table 4 - Liveliness Index 3-ply Sample Yarns ........................................... 38
Table 5 - Sample of Raw Yarn Data (2-ply) ................................................ 43
Introduction

Today’s handspinner is acutely aware of integral qualities of fibre, which allow them to describe and ultimately predict the behaviour of their finished yarns. Terms such as angle of twist (AOT), twists per inch (TPI), and wraps per inch (WPI) are common attributes that appear in many of the trade journals available today, PLY and SpinOff being two of the most popular. Each of these can be discretely measured by the handspinner and used in explicative terms to describe the yarn itself, and in comparative terms to compare disparate yarns or yarns of the same fibre, but spun at different times as part of a larger project. Angle of twist (AOT) refers to the angle at which the plies appear to lay relative to the axial length of the yarn sample. In general, the greater the angle, the less soft the yarn will be, or more dense and hard. Twists per inch (TPI) refers to the number of rotations of the yarn (whether clockwise or counter clockwise) in a unit of measure, in this case, one inch. The more TPI, the higher the AOT, and consequently, the less soft the yarn will be. Wraps per inch (WPI) refers to the thickness or diameter of the yarn as it is laid side by side within a unit of measure, in this case, again, one inch. In general, the more WPI, the finer the yarn. Each of these can easily be measured with simple tools by the handspinner.

Industry standards and studies, by contrast, offer limited usefulness in practice to the handspinner. Where the chemical and “anatomical” structures of various animal and plant fibres expand the knowledge and awareness of handspinners, close analysis and

---

1 The common method for calculating TPI involves counting the number of thread bumps in one inch of yarn. The value is then divided by the number of plies in the yarn to derive the final TPI count. However, this method does not take into account the effect of take-up, elasticity, or resiliency. Take-up, or shrinkage, is a direct result of elasticity and will inflate the number of twists and increase the AOT. Normally this indicates a denser, harder, and tightly twisted yarn. See Appendix A for suggestions for further study.
presentation of metrics such as tensile strength breaking point, stress-strain curves, compression, tenacity, and coefficient of friction lose their real-world applications for production methods dominated by hand-manipulation. Discoveries of new fibre properties and relationships benefit industry greatly in very real ways: faster and more efficient production (from fibre preparation to end-use fabric), reduction of waste, ability to source fibres better suited to end-products, wider range of fabric design possibilities, and new synthetic fibres, among others. Concepts of elasticity and resiliency, for example, are hidden within a wider range of fibre strength characteristics and often are focused on the fibre itself rather than the yarn. According to MG Hunson, yarn can be and is measured for strength, but because the strength of the yarn relies on friction introduced by twist and dynamics beyond the length of individual fibres, it is left "out of scope" (Hunson, 2009). By contrast, the yarn itself is of primary importance to the craftsman\(^2\). Fibre characteristics play a secondary role and only insofar as they assert discernible differences in the final yarn.

The perceptive capabilities for the craftsman, however, are limited to the five senses and whatever tools can be procured by a relatively modest range of financial resources: rulers, scales, magnifying lenses, etc. Other descriptive terms are not as easily ascertained, require more sophisticated equipment to quantify, or are not usually measured by the handspinner. These are, nonetheless, part of the preferred vocabulary for describing yarn. Terms such as crimp, bounce, memory, and softness are not measurable as such, but can be derived directly from the above measurements, such as AOT, or as some sort of relationship between one or more measurable qualities, such as TPI and

\(^2\) For the purposes of this study, the term ‘craftsman’ encompasses those working with fibre and yarn, including handspinners, handknitters and crocheters, and handweavers.
ELASTICITY AND RESILIENCY IN HANDSPUN YARNS

WPI, to determine relative number of twists for a given diameter of yarn. The fewer the WPI and thicker the yarn, the softer it will be. Crimp, however, is a result of specialized mechanisms produced in the fleece of sheep and the lock structure of the fleece itself. The spring-like wave is measured in the lock of the fleece before it is processed into a fibre preparation. Crimp can be measured relatively easily as the number of waves per unit measure (usually one inch). However, the effect of fleece crimps per inch (CPI) in the final yarn – whether a greater number or lesser number – is not as easily quantifiable and is more general in nature. For example, Beth Smith explains that sheep breeds with a “wonderful crimp structure [in their wool], have a natural elasticity and memory built into them” (Smith, 2013). The implication here is that the more crimps per inch, the more elasticity and more memory the resulting yarn will have, whereas the relationship between crimp, elasticity and memory (or resiliency) could be made more clear if the handspinner were to measure the crimp of a specific fleece and subsequently measure the elasticity and memory of the yarn. In the case of blended and carded preparations, the crimp of constituent wool or the absence of wool altogether obscures the relationship and leaves only elasticity and resiliency (or memory) as observable characteristics. Crimp, then, is generally inadequate for quantifying elasticity vis-à-vis resiliency in describing handspun yarns, especially when the source fibre has been processed and/or blended with other source fibres either commercially or by the handspinner themself.

It is this relationship between elasticity (the amount that the yarn will stretch) and resiliency (the tendency of the yarn to return to its original state after undergoing stress) that is the focus of the study here. Further, the study attempts to quantify the relationship in providing a metric with which to describe handspun yarn, much like AOT, TPI, and WPI: liveliness. Descriptors do well to impart an immediate impression and evaluation of
a yarn, a resumé of its potential, so to speak, while liveliness moves beyond the skein itself and provides the handspinner, handknitter, and handweaver with a more concrete indicator of the success of the yarn in the chosen final project where liveliness is a critical component.

Elasticity, Resiliency and Liveliness

Parameters

Any directed effort in understanding aspects of a sphere of knowledge benefits greatly from a common understanding of terms and parameters used throughout the study. The phenomena of elasticity and resiliency were first noted by British physicist Robert Hooke in 1678, who “sought to demonstrate the relationship between the forces applied to a spring and its elasticity” (Williams, 2015). The dynamics of stress and strain are presented together in a stress/strain curve or graph. The stress/strain curve graphs the strain, or distortion, of a material in response to a stress or force in some direction relative to the material being tested. In its entirety, the graph shows the resulting strain of the material as it approaches a point of permanent distortion and finally ends at the rupturing point of stress on the material. In the textile industry, this is known as tenacity when expressed as strength divided by the material’s density (Unknown, 2018).
Hussain illustrates that the elastic modulus (or elasticity) is the region of the stress/strain curve "where Hooke’s law holds" (Hussain, 2012). In other words, at any point between initial stress and yield stress (the point at which the yarn undergoes permanent distortion), the yarn will return to its original length. It is this area of the curve that most concerns the craftsman vis-à-vis elasticity and resiliency.

Common terms among handspinners reflect qualitative terms rather than quantitative. For the purposes of this study, bounce and yarn memory can be understood to be alternate descriptions of the resiliency of the yarn, how readily the yarn will stretch and retract. All references to elasticity, resiliency, bounce, and memory are directed to yarn spun from a source fibre and not qualities of the fibre itself. Numerous studies of wool and animal fibre qualities exist and serve as a broad basis of understanding. For the handspinner, testing individual fibres is at best impractical, if not nearly impossible, and offers little in the way of evaluating yarn dynamics for non-industrial applications.
In order to isolate elasticity and resiliency, two control fibres were chosen for their lack of natural elasticity: alpaca and silk. Alpaca fibre has little crimp, and consequently little elasticity. Tussah silk was chosen for a similar lack of crimp, elasticity, and resiliency. Second, these fibres were chosen because they are readily available for purchase by the handspinner. Two test fibres were chosen to blend with the control fibres in order to modulate the elasticity and resiliency in the final test yarns: merino wool and cormo wool, respectively. A thorough discussion of fibre choice and selection will be handled in a later section.

Sixteen sample groups will form the basis of the comparison of elasticity and resiliency. Each group is classified by the amount of control vs test fibre and forms the basis of the data pool for analysis: 100%, 90%, 80%, 70%, 60%, 50%, 0% control fibre. Two additional increments of 34% and 17% control fibre were added to the silk sample groups to see if larger percentages of wool behaved similarly. In lower concentrations of silk, the test fibre had a greater effect on the elasticity of the yarn; the two additional increments helped to fill out an otherwise large leap of elasticity in the silk series.

In preliminary observations, 5% increments of control fibre were too small to produce clear test results. In one example, the elasticity of a 100% vs 90% alpaca blend yarn differed by 1%. However, greater differences in 10% increments clarified trends as seen in the final data. Although not directly related to elasticity, the original proposal limited the yarns to 50% and above in order to maintain the "character" of the control fibre. For the purposes of this study, character is defined as no less than equal amounts of control and test fibre. Therefore, yarns containing less than 50% control fibre were not observed; they fell outside the range of the character of alpaca and silk.
Further, each group consists of a 2-ply and 3-ply yarn created from the same singles thread. In addition, knitted and woven garment samples made from each of the 2-ply and 3-ply yarns provide a backdrop for evaluating elasticity and resiliency of the yarns in a finished fabric. For each of the yarns in the sample groups, a number of metrics have been collected and used to determine elasticity gains, resiliency reformation, and ultimately the liveliness index for each yarn. These include the amount of length gained after an hour of standard stress, amount of length reabsorbed one minute after stress has been removed, the amount reabsorbed after two minutes, and again after one hour. Garment samples have been subjected to stress for six hours and metrics have been recorded for area gained, area reabsorbed after one minute, and again after one hour of rest.

Given a common understanding of fibre from the perspective of the handspinner, it is expected that yarns with more crimp or wool will produce the most elastic and resilient yarns and (most likely) the most elastic and resilient garment samples. Additional expectations will be left to later sections and further analysis.

Where some parameters have been expanded, others have been eliminated from the final design of the study due to preliminary analysis and testing of mock sample groups. The original plan for this study included a comparison of a complete set of samples where the yarn had been weighted during finishing to yarns left to air dry without weights. Preliminary samples revealed that the weighted samples removed or dampened much of the effect of elasticity and resiliency. More accurately, weighted finishing tended to more or less permanently extend the length of the yarn while preventing any resiliency reformation. While this is an interesting phenomenon and may open avenues for further
study, removing 50% of the test metrics would tend to promote confusion of the results rather than clarify the findings. Therefore, the entire sample series was left out of the final experiment design. In addition, the original design prescribed that the test yarn lengths would undergo stress for two hours before removing the stress and testing for resiliency reformation. It was found by comparing stress times of one hour and two hours that there was no significant difference. Therefore, the stress period for yarns was reduced to one hour in the final design. Similarly, garment samples were originally scheduled for 48 hours of stress before being released and measured in the post-stress phase. Again, comparisons with shorter times revealed that six hours of stress produced the same strain results during the preliminary design validation phase. Therefore, the stress period for woven and knitted garment samples was reduced to six hours of continued stress. Finally, two methods of stress for yarn were compared during the test validation period. The first produced stress by pinching and stretching the yarn by hand; the second created stress by using standard weights. Although the preliminary results were within a reasonable range of each other, it was determined that a standard time and weight would be a more reliable and repeatable methodology for the study. The weighted method was included in the final design.

**Equipment**

Relatively simple equipment was used in the study. An AWS (American Weigh Scale) electronic scale Model SC-501A was used to weigh fibres for the various sample groups. The scale was chosen for its historical reliability and targeted range of <500g. A small paper bin was used to contain the fibre while weighing. For carding and spinning preparation a Patrick Green Supercard drum carder was used. The electric card promoted
even and consistent carding over the large amount of fibre used in the study (3 lbs). A Schacht Matchless (Cherry Anniversary Edition) double-treadle spinning wheel was used for all spinning and plying. A yardstick attached to the mother-of-all served as a static gauge to maintain a consistent drafting length. A nylon drive band was used in place of a natural fibre to hedge against slippage, breakage, and wear. The poly surface allowed for consistent grip and less slippage along the whorl, ensuring consistent and accurate twist calculations. To divide equal amounts of the singles thread for the 2-ply and 3-ply, or 5 plies in total, a Schacht yardage counter was used together with a BobbinsUp drill bit and bobbin. A standard niddy noddy and Schacht Ultra Umbrella swift were used for winding, skein measuring, and sample skein preparation. Standard TPI, WPI and AOT gauges and charts were used to measure the respective yarn metrics, including Donegan V388-1 Thread Counter Linen Tester. Stress was applied to the yarn samples (both 2-ply and 3-ply yarns) using a knitting machine claw weight and standard stainless steel s-hooks. Both weighted and hand-stretched samples were measured with a standard yardstick. Two knitting machines of differing gauges were used to prepare the knitted garment samples. A Brother KH970 standard gauge (4.5 mm) knitting machine (and ribber attachment) was used for the finer 2-ply knitted swatches and a Silver Reed SK860 medium gauge (6 mm) knitting machine was used for the thicker 3-ply swatches. The woven samples were prepared with a vintage 4” Weavette pin loom purchased on eBay. Stress was applied to the garment samples using two opposing triangular weight hangers used for machine knitting. A standard 6” ruler was used to measure elastic gain and resiliency reformation. A standard kitchen timer was used to ensure consistent stress periods and incremental resiliency reformation checks throughout the testing phase.
Fibre Preparation

_Fibre Selection_

Fibre was chosen to accentuate the difference between elastic and non-elastic fibre in order to modulate the amount of both and measure the resulting elasticity in the yarn. In the strict sense, this design diverges from the classical control vs test variable, but cannot be avoided since the whole, in this case, is made up of its parts, meaning that adding more test fibre to a control quantity necessarily changes the outcome in the yarn and the effects of one cannot be isolated from the whole.

Because elasticity and resiliency are manifestations of stored energy we can look to the mechanism of storage and vary that to find patterns in handspun yarn. One method, not implemented here, would be to find sheep breeds with similar crimp structures and varying amount of CPI. In the method used here, elasticity and resiliency are seen as simply the number of crimps in a given length yarn (regardless of the source), the crimps can come from one fleece compared to another or the same fleece by modulating the amount in the blend used to spin the yarn. To offset the amount of crimp introduced by the test fibre, the study uses control fibre that doesn’t introduce any additional crimp (or as little as possible) to the final blend: alpaca and tussah silk.

Samples of each fibre were tested for intrinsic elasticity and resiliency in order to establish a baseline for the amount of elastic gain and resilient reabsorption the fibres may or may not impart to the blended yarns. The alpaca used in the study does have a small amount of crimp and elasticity. With a very low CPI of 4, alpaca realized an elasticity of 1%. However, of the ¼ inch of elastic gain, alpaca was 100% resilient, returning to its original measured length. Given that the same source of alpaca was used
throughout the sample groups, its influence across the sample pool will be the same and can be considered when necessary. Merino was chosen to blend and modulate because of its CPI: 11 for the test fleece. Elasticity for the sample fleece was 19% and resiliency was 73%. Tussah silk is completely devoid of crimp and realized 0% elasticity and resiliency. It was paired with another high crimp wool: cormo. The cormo fleece has a higher CPI than the merino at 15. Its elasticity for the sample was similar the merino test fleece, however. Elasticity was calculated at 18% and resiliency 86%.

Fibre Preparation

In total there are 16 sample groups. Samples 1-7 are varying percentages of alpaca fibre/merino wool fibre. Samples 8-16 are varying percentages of tussah silk/cormo wool fibre. All samples were processed the same way with one small variation in the tussah silk/cormo sample groups.

The wool fibre was scoured and washed to remove oil and dirt. The merino fleece was scoured in small sections of about 57g each. Each section was wrapped in a netting material to make handling more efficient, then placed in a sink with 150°F water. The water was mixture of tap water and water boiled in an electric tea kettle. The fleece was allowed to soak for 30 minutes. In the second bath, Unicorn Power Scour was used as detergent along with 150°F water. The recommended amount of detergent was used and adjusted for smaller quantities. The fleece was left to soak for an additional 25 minutes. After soaking, the fleece was rinsed in hot rinse water (to discourage felting) until clear. The fleece was hand squeezed without wringing (again to prevent felting) to remove as much remaining water as possible. The fleece was left to air dry on an open mesh rack.
The cormo fleece was separated into locks and laid out before wrapping them in mesh bags of similar weight of 57g. Care was taken to keep the orientation of tips to tails for later processing. Otherwise, the cormo fleece was processed using the above method.

![Cormo Locks](image)

*Figure 2 - Cormo Locks*

The alpaca fibre was processed using above method as well. However, because the alpaca fleece had little oil and dirt, only a 1/3 of the recommended scouring solution was used in the second bath. The temperature of the water was reduced to about 100°F, but soaking times remained the same.

After completely drying for a number of days, the fibre was weighed into 30g bundles according the percentages of the target sample group. Three bundles of 30g each were weighed for each of the sample groups to allow for the number of yards needed for each of the 2-ply and 3-ply sample yarns.

<table>
<thead>
<tr>
<th>Sample Group</th>
<th>Alpaca</th>
<th>Merino Wool</th>
<th>% Alpaca</th>
<th>% Merino Wool</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30g</td>
<td>0g</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>27g</td>
<td>3g</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>24g</td>
<td>6g</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>21g</td>
<td>9g</td>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>18g</td>
<td>12g</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>15g</td>
<td>15g</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>0g</td>
<td>30g</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

*Table 1 - Alpaca Sample Groups*
Table 2 - Tussah Silk Sample Groups

Each 30g bundle was then drumcarded three times to ensure even and homogenous blending. In the alpaca blends, the fibres were premixed in the intake tray of the electric drum carder (see Figure 3 - Alpaca/Merino Premix). In the silk blends, the cormo locks were opened up using a flick carder to remove nep and shorter fibres before being placed in the intake tray along with the silk. The first batt was removed and split into eight sections. Each section was randomly selected and spread over the intake tray in the second pass to ensure efficient carding. The batt was removed from the drum in a roving form by using a diz to remove the fibre in a long spiral strip. In the third and final pass, the roving was angled across the intake tray from side to side (see Figure 4 - Third Pass of Carding). This allowed small inconsistencies to be distributed across the batt instead of concentrating them in one area. The final batt was doffed using the roving technique and set aside with the sample group for spinning. The tussah silk blends were handled in the same way with one difference in method. The cormo locks were fed into the drum carder butt ends first. The batts and roving were also oriented so that the cormo fibres were presented butt ends first.
Spinning Method

The spinning method and parameters remained identical for each of the sixteen sample groups, both in the spinning and plying. A Schacht Matchless wheel was configured for Scotch tension, which allowed for a finer control over tension over the entire 90g of fibre for each sample group. A medium whorl was used so as to allow for more treadles and time to manipulate the source fibres and to maintain consistent twists per inch. A polyurethane drive band was essential in ensuring that there was no slippage of the drive band, which can cause inconsistent twists entering the singles. Because the poly drive band is thicker than the whorl channel, the ratio of the wheel was altered from...
its specification. Given the thicker diameter of the poly drive band the working ratio of
the whorl measured at 10.5:1.

Twists per inch were kept consistent by employing a few simple techniques. Treadles were
maintained per draft length by counting, thereby maintaining consistent twists per inch: 10
treadles for the singles thread, six treadles for plying the 2-ply yarn, and five treadles for
plying the 3-ply yarn. A yardstick was used to maintain a consistent draft length: 13 inches
for the singles thread, 15 inches for the 2-ply, and 16 inches for the 3-ply.

An empty bobbin was used for each sample group, which helped maintain similar spinning
dynamics across the 16 sample groups. The singles thread was laced back and forth
across the flyer hooks to disperse the higher tension but was abandoned after the first 30g
bundle due to the buildup of the singles yarn on the bobbin. A higher tension was used in the
plying process for smoothness and consistency of plying twist.

The spinning technique itself was based on a worsted style of spinning influenced by crimp
similar to how Bitsy Cohen describes in PLY when spinning from the lock (Cohen, 2015). The
method utilizes the compression qualities of a true worsted inchworm method while
maximizing the effects of crimp. The singles thread is laid over the upturned active hand so
the palm faces upward with the point of the drafting triangle over the little finger. The twist
is held back by downward pressure applied to the fibres as they angle down over the little finger. The slight pressure allows the crimp to be extended before being locked into the twist. As the twist enters the drafting triangle the hands move backward to create more thread until the drafting length is achieved. The construction phase of the thread encompasses all but the last treadle. The final treadle is
used to wind the length of thread onto the bobbin. Once an equilibrium is reached between the tension setting and action of drawing the fibre backwards, a sort of continuous motion can be achieved, eliminating the inch worm method of pirching and pulling to achieve a worsted outcome.

Figure 5 - Continuous Worsted Technique

At this point all the fibre is on the bobbin. In order to ply equal amounts of 2- and 3-ply yarn, a total yardage count is necessary. The yarn was threaded through a yardage counter before winding off the bobbin onto a Schacht Super Umbrella swift. Once the total singles yardage was noted, five equal amounts were divided using a cordless drill and a BobbinsUp drill bit and bobbin. The singles thread was threaded back through the yardage counter and monitored as the drill filled an extra empty bobbin. The bobbins were mounted on a standard lazy kate. Ply twist was calculated to require six treadles at a 15-inch draft distance for 2-ply and five treadles at a 16-inch draft distance for 3-ply yarn.
**Finishing Method**

All yarn samples were finished using the same method. For each sample group, both 2-ply and 3-ply skeins were wound onto a Schacht Super Umbrella swift after plying. The skeins were loosely tied around all strands (as opposed to a figure eight tie between strands) so as not to hamper drying and expected shrinkage. They were placed in a salad spinner along with 2 litres of very warm (~100°F) water and about 20 ml of SOAK liquid. The salad spinner was covered, and the skeins were left to soak for one hour. The skeins were removed from the spinner and thoroughly rinsed with very warm (~100°F) water until the water ran clear and no soap residue was observed in the rinse water. The skeins were subsequently hand squeezed to remove as much water as possible before placing back into the spinner. The skeins were spun for about 30 seconds to extract as much water as possible. Finally, each skein was hung on an S-hook and left to air dry completely. The drying time varied slightly for each of the blends and was not noted in the final data pool, nor used in any analysis.

**Measuring Technique**

Simple tools and techniques were used to measure the test fibres, test skeins (for shrinkage only), test yarns and test garment samples for elasticity and resiliency. Small samples of individual control and test fibres were measured for CPI, elasticity, and resiliency. A small lock or section of test/control fibre was measured for crimps per inch using the linen tester. The samples were then tied at each end of the staple length with cotton cord and suspended over a ruler. The length between the tied points was recorded as *start length* in the raw data. The sample was stretched and held in place by looping the cord around weights. After two hours the sample was measured again for elasticity and
recorded as 2 hr elastic length in the raw data. The sample was released and immediately measured for length. This was recorded as immediate resiliency in the raw data. The sample was allowed to relax and was measured again at one minute, two minutes, and one hour. These were recorded as 60 sec resiliency, 120 sec resiliency, and 1 hour resiliency in the raw data.

![Figure 6 - Source Fibre Elasticity Test](image)

Wet finished sample skeins were not monitored for drying times, as noted previously. However, the average wet length of each skein and the average final dry length of each skein were noted in the final data and provided insight into the elasticity of the yarn itself.

Each yarn was measured using a hand stretch technique prior to finishing and subjected to a weighted technique after wet finishing/drying. A section of yarn was laid on a yard stick and straightened, but not stretched to remove any natural or irregular curves due to spinning stress or skein ties (see Figure 7 - Yarn irregularity).
The yarn was pinched using the thumb and index finger forming a 10" length of yarn between the hands. The yarn was then stretched as much as possible until the yarn would not stretch without a great deal of opposing stress. The amount of actual stress was neither measured nor noted. The length, however, was measured and recorded. This constitutes the *hand stretched elastic length* in the raw data.

Each yarn was measured for elasticity using a weighted method. Two loops were tied in a length of yarn. In addition, two control points were created by tying two knots 10" apart using a cotton cord of contrasting colour. The yarn was hung at one end suspended on an S-hook. At the opposite end a standard knitting machine claw weight was attached below the lower control point. This created a stress force of 110g and allowed the yarn to fully extend without breaking (see Figure 8 - Weighted Elasticity Test). In preliminary testing heavier weights created a stress that tended to deform the yarn, pushing it beyond the point at which Hooke’s law holds, the Hooke zone. The yarn was left to hang under stress for one hour. The distance between the control points was measured and recorded as *1 hr weighted length* in the raw data. The yarn was removed from the test environment and left to relax for a series of timed intervals: one minute, two
minutes, and one hour. The length of yarn between the control points was measured and recorded as 60 sec resiliency, 120 sec resiliency, and 1 hr resiliency, respectively.

Figure 8 - Weighted Elasticity Test

Both 2-ply and 3-ply yarns were formed into 4" woven and knitted samples and measured for elasticity. Both woven and knitted samples were measured before stress was applied, and calculated as simple area = width x length. These were recorded as start width, start length, and start area in the raw data. Woven samples were hung with standard triangular claw weight hangers used in machine knitting. A standard 1.2 lb weight used in machine knitting created the stress. For the woven samples, only linear stress was created (see Figure 9 - Woven Sample Test). For knitted samples, stress was also created in the width by attaching double point needles to the edge of the samples. The needles were stiff enough to provide stress as they were kept in place in the claws of the weight holders at the top and bottom (see Figure 10 - Knitted Sample Test). Both
woven and knitted samples were subjected to six hours of stress. Area was calculated by measuring the width across the top of the sample as it was attached the upper claw and the length between the claws. These were recorded as 6 hour weighted length, 6 hr weighted width, and 6 hr weighted area in the raw data. All samples were allowed to rest for one minute. Length and width were noted but not included in the raw data. After one hour, length, width and area were measured and calculated. These were recorded as 1 hr resiliency length, 1 hr resiliency width, and 1 hr resiliency area.

Figure 9 - Woven Sample Test

Figure 10 - Knitted Sample Test
All calculated metrics were derived using Microsoft Excel formulas. Elasticity was recorded as a raw gain in length or area by subtracting the initial value from the value recorded after the stress period. These appear as *gain* and *gain area* in the raw data. Elasticity was also recorded as a percentage of the start length or area. These appear as % *gain* for both yarns and garment samples in the raw data. Resiliency was derived as a percentage of the length or area after the stress period. If the samples retracted or reabsorbed the elastic gain, the sample would be 100% resilient\(^3\).

*The Findings*

Generally, the findings confirmed the more of the elastic fibre in the source blend, the more elastic and resilient the yarn will be. Resiliency wasn’t dependent on either elasticity nor amount of elastic fibre in the blend. Just over 50% of the samples were 100% resilient regardless of elasticity gain, and all the yarns had very good elasticity. Just over 25% of the samples had very low elasticity, which isn’t surprising given the high percentage of inelastic fibre in some of the yarns. The garment samples did exhibit more extreme variations between the two types of garment samples. The knitted samples were much more elastic than the woven samples, but the woven samples were much more resilient. Very few of the knitted samples were 100% resilient, at least not in the 1 hour resting period, suggesting that knitted samples need more time to recover or that the knitted samples were stressed to the point of partial deformation. One knitted and two woven samples were more resilient than they were elastic, meaning that the samples

---

\(^3\) As another example, consider a 10-inch length of yarn. After the stress period, the yarn is measured as 12 inches. It has gained 2 inches of elasticity. After the resiliency period, the yarn is measured as 11 inches. It has reabsorbed 1 inch of the 2 inch elastic length. This yarn would be 50% resilient. Consider also a yarn that has an elastic length of ¼ inch. If it has reabsorbed the ¼ inch, it would be 100% resilient. Finally, if that same sample reabsorbed 3/8 inch (*more* than its elastic length), the sample would be 150% resilient.
reabsorbed more length/area than was gained in elasticity. Most likely these were due to measuring errors rather than a physical phenomenon where the stress phase triggered further resilient absorption at a deeper structural level.

*Observations*

As each of the alpaca and silk sample groups were hanging to dry, the wet length of the skeins were fairly close in length, while the dry length was significantly different (see Figure 11 - Alpaca Skeins and Figure 12 - Silk Skeins). This may suggest that water has a measurable effect on the elasticity\(^4\). The only exceptions were the 100% wool skeins, where the lengths were significantly shorter even when wet. If the skeins themselves were the only measure of elasticity, the regular introduction of elastic fibre to the blend can be seen directly in the length of the fully dried skeins.

\textit{Figure 11 - Alpaca Skeins}

\(^4\) The sample skeins were not measured for weight after spinning, after removing excess water and before hanging to dry. Water has a weight of 1g per 1ml effectively adding some weight to the skeins as they dried. See Appendix A for suggestions for further study.
The 100%, 90%, 80% wet silk skeins hung at the same length, unlike the rest of the series where they hung progressively shorter. This could be due to wool elasticity, specifically; wool may have less effect on silk when wet than alpaca. But, when dry the skein lengths fit into a regularly shorter progression, albeit still closer to each other in length than the group as a whole. It could be that wool has a stronger influence on the alpaca than the silk at lower percentages.\textsuperscript{5}

Results

It is very clear from the data and observations that crimp is a major source of elasticity (see Figure 13, Figure 14, and Figure 15 - Resiliency (Weighted)). Although current journal articles relating to elasticity seem focused on 100% fibre sources (as opposed to blended fibre sources and yarn), the dynamic of crimp within a blend is just as measurable. Revising the understanding of the relationship of crimp to elasticity, not as

\textsuperscript{5} In Figure 12, the left most skein has been inadvertently cut off. This is the 100% Tussah Silk skein that hung at the same length at the skein to its right (90% Tussah Silk / 10% Cormo Wool).
one higher CPI fibre over another but as the number of crimps in the final yarn, serves both 100% fibre/yarns as well as blended fibres and yarns.

*Figure 13 - Elasticity Gain (Weighted)*
Figure 14 - Elasticity Gain (Hand-stretched)

Figure 15 - Resiliency (Weighted)
ELASTICITY AND RESILIENCY IN HANDSPUN YARNS

One of the original questions that was posed for the study was: how much does elasticity in yarn affect elasticity in the garment samples? After reviewing the data there does seem to be a correlation between the elasticity of the yarn and the structure of the knitted garment samples. The data show a similar trend in both yarn and garment elasticity/resiliency (see Figure 16 - Elasticity Gain Alpaca Yarn and Knitted Garment and Figure 17 - Elasticity Gain Silk Yarn and Knitted Garment). However, the data is less clear when comparing the same results in the woven garment samples (see Figure 18 - Elasticity Gain Alpaca Yarn and Woven Garment and Figure 19 - Elasticity Gain Silk Yarn and Woven Garment). Certainly, one can say that knitted garments are more elastic, but not in a way that can be reliably predicted given the elasticity of the yarn. Meaning that given a desired amount of elasticity in the final knitted garment, it would be difficult to determine how much elastic fibre to introduce into the blend. A further study with a greater data pool might reveal a clearer correlation or path to predicting the behaviour of the garment given the elasticity/resiliency of the yarn. To a greater or lesser degree, the structure dynamics of finished fabric are clearly influencing elasticity and resiliency more than what is realized in the constituent yarns.
Figure 16 - Elasticity Gain Alpaca Yarn and Knitted Garment

Figure 17 - Elasticity Gain Silk Yarn and Knitted Garment
Elasticity Gain - Alpaca

Yarn and Woven Garment Sample

- 2-ply Alpaca
- 3-ply Alpaca
- 2-ply Alpaca Woven
- 3-ply Alpaca Woven

Figure 18 - Elasticity Gain Alpaca Yarn and Woven Garment

Elasticity Gain - Silk

Yarn and Woven Garment Sample

- 2-ply Silk
- 3-ply Silk
- 2-ply Silk Woven
- 3-ply Silk Woven

Figure 19 - Elasticity Gain Silk Yarn and Woven Garment
Conclusions

What is lacking in common understanding of elasticity and resiliency—the main forces at play in yarn—is the relationship between the two and how that relationship might affect the final project. Unfortunately, the data here doesn’t suggest—or there are not enough data points to reveal—a relationship in the final garment. However, an understanding of the relationship between the two can be attempted. Colloquial terms already exist for the very same relationship; bounce, memory, and springy appear frequently in trade journals. But there is no attempt to quantify the dynamic. I would like to suggest that liveliness can be quantified.

The approach suggested here is to plot the raw percentages of elasticity and resiliency. This alone isn’t enough to derive a value for liveliness. What is needed is relative scale of more vs less lively. If we can view not-resilient and not-elastic as 0,0 and 100,100 as the positive extreme of resilient and elastic in terms of a coordinate system, we see that a line dividing the range in two would do nicely to visualize more elastic (one side of the line) vs less elastic (the opposite side of the same line). The challenge is how to orient the line that enhances the ability to visually distinguish liveliness among the yarns in the graph. A line that is parallel to either the resiliency axis (x-axis) or the elastic axis (y-axis) does not adequately take into account both forces. However, a diagonal line passing through the upper left (not resilient, but elastic), 50,50 (equally resilient and elastic), and 100, 0 (resilient, but not elastic) would do nicely to visualize both forces and separate less lively from more lively yarns.

To provide some context, flax yarn would be graphed near 0,0 whereas yarn made from rubber bands would be near 100,100. If we use the 45° line to delineate more from
less, flax could be given a liveliness index of -100 and rubber band yarn a value of +100.

In order to assign a liveliness index to other intermediate combinations of elasticity and resiliency, we can derive the value as a distance from the dividing line. In this model, many yarns can have the same liveliness index as their values fall along a parallel line to the dividing line. This means that any yarn that is close to 100% resilient will be a positive liveliness value and fall above the dividing line, essentially favoring elasticity over resiliency (see Figure 20 - Liveliness Graph).

Table 3 and Table 4 show elasticity gain, percentage resiliency, and the resulting liveliness index for both 2-ply and 3-ply yarns in the sample groups. Consider samples #3.1, #11.1, and #11.2. #3.1 and #11.1 have a different percentage of control fibre and test fibre: 80% Alpaca/20% Merino Wool, 70% Tussah Silk/30% Cormo Wool, respectively. Samples #3.1 and #11.1 are 2-ply yarns, whereas Sample #11.2 is a 3-ply yarn. However, each has a liveliness index of +10. A closer look at the constituent dynamics of elasticity and resiliency will reveal that each exhibits a differing amount of elasticity and resiliency, but together the dynamics result in the same index. For example,
Sample #3.1 (20% Merino Wool) reached an elasticity gain of 18%, but only realized 93% resiliency reabsorption, whereas Sample #11.1 (30% Cormo Wool) exhibited a 10% elastic gain but was more resilient at 100% reabsorption. The former sample extended less but sprung back more; the latter sample vice versa. The liveliness index is able to synthesize "memory, bouncy, spring" into a quantitative value that can be used to compare yarns of disparate fibre content without favoring one source fibre over another. In fact, a strength of the liveliness index is that it can document the interactions of the source fibres as they exert their influence on the final yarn.

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Elastic Gain</th>
<th>% Resiliency</th>
<th>Liveliness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1.1</td>
<td>8%</td>
<td>100%</td>
<td>+8</td>
</tr>
<tr>
<td>#2.1</td>
<td>13%</td>
<td>100%</td>
<td>+13</td>
</tr>
<tr>
<td>#3.1</td>
<td>18%</td>
<td>93%</td>
<td>+10</td>
</tr>
<tr>
<td>#4.1</td>
<td>19%</td>
<td>93%</td>
<td>+12</td>
</tr>
<tr>
<td>#5.1</td>
<td>24%</td>
<td>100%</td>
<td>+24</td>
</tr>
<tr>
<td>#6.1</td>
<td>25%</td>
<td>95%</td>
<td>+20</td>
</tr>
<tr>
<td>#7.1</td>
<td>35%</td>
<td>100%</td>
<td>+35</td>
</tr>
<tr>
<td>#8.1</td>
<td>5%</td>
<td>100%</td>
<td>+5</td>
</tr>
<tr>
<td>#9.1</td>
<td>6%</td>
<td>80%</td>
<td>-14</td>
</tr>
<tr>
<td>#10.1</td>
<td>8%</td>
<td>100%</td>
<td>+8</td>
</tr>
<tr>
<td>#11.1</td>
<td>10%</td>
<td>100%</td>
<td>+10</td>
</tr>
<tr>
<td>#12.1</td>
<td>13%</td>
<td>100%</td>
<td>+13</td>
</tr>
<tr>
<td>#13.1</td>
<td>23%</td>
<td>94%</td>
<td>+20</td>
</tr>
<tr>
<td>#14.1</td>
<td>24%</td>
<td>89%</td>
<td>+13</td>
</tr>
<tr>
<td>#15.1</td>
<td>30%</td>
<td>92%</td>
<td>+22</td>
</tr>
<tr>
<td>#16.1</td>
<td>45%</td>
<td>94%</td>
<td>+39</td>
</tr>
</tbody>
</table>

*Table 3 - Liveliness Index 2-ply Sample Yarns*
<table>
<thead>
<tr>
<th>Sample</th>
<th>% Elastic Gain</th>
<th>% Resiliency</th>
<th>Liveliness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1.2</td>
<td>8%</td>
<td>100%</td>
<td>+8</td>
</tr>
<tr>
<td>#2.2</td>
<td>10%</td>
<td>88%</td>
<td>-3</td>
</tr>
<tr>
<td>#3.2</td>
<td>18%</td>
<td>100%</td>
<td>+18</td>
</tr>
<tr>
<td>#4.2</td>
<td>21%</td>
<td>100%</td>
<td>+21</td>
</tr>
<tr>
<td>#5.2</td>
<td>19%</td>
<td>93%</td>
<td>+12</td>
</tr>
<tr>
<td>#6.2</td>
<td>33%</td>
<td>96%</td>
<td>+29</td>
</tr>
<tr>
<td>#7.2</td>
<td>31%</td>
<td>96%</td>
<td>+27</td>
</tr>
<tr>
<td>#8.2</td>
<td>4%</td>
<td>67%</td>
<td>-30</td>
</tr>
<tr>
<td>#9.2</td>
<td>5%</td>
<td>100%</td>
<td>+5</td>
</tr>
<tr>
<td>#10.2</td>
<td>5%</td>
<td>100%</td>
<td>+6</td>
</tr>
<tr>
<td>#11.2</td>
<td>10%</td>
<td>100%</td>
<td>+10</td>
</tr>
<tr>
<td>#12.2</td>
<td>16%</td>
<td>100%</td>
<td>+16</td>
</tr>
<tr>
<td>#13.2</td>
<td>25%</td>
<td>100%</td>
<td>+25</td>
</tr>
<tr>
<td>#14.2</td>
<td>21%</td>
<td>100%</td>
<td>+21</td>
</tr>
<tr>
<td>#15.2</td>
<td>33%</td>
<td>92%</td>
<td>+25</td>
</tr>
<tr>
<td>#16.2</td>
<td>43%</td>
<td>94%</td>
<td>+37</td>
</tr>
</tbody>
</table>

Table 4 - Liveliness Index 3-ply Sample Yarns

I've worked on developing a website where craftsmen can test their handspun yarns or acquired yarns to find out their liveliness index. At the time of this study users can add their measurements of elasticity and resiliency according to instructions on the website. Users are also able to see where their yarn falls within a graphic representation of liveliness. In addition, the data from this study can be superimposed to provide context and additional data points. Finally, users will be able to see the study data as an absolute graph or relative graph. In other words, many yarns in this study would fall closely to one another in the graph due to similar dynamics in the yarn. However, if you look at the data relative to the least lively to the most lively in the dataset, the graph would allow users to see a clearer distribution of lively yarns and situate theirs among the test data more easily.

The website can be found here: [http://www.enigamigis.com/liveliness/index.html](http://www.enigamigis.com/liveliness/index.html).

Additional improvements will be added to the website as time allows: adding the ability to collect data and present user-provided values, instructional videos for measuring elasticity, a predictive engine for how the yarn might behave in a garment, and predictive suggestions for end-uses based on elasticity/resiliency.
Figure 21 - Liveliness Calculator Website
References


Appendix A

Areas for Further Study

For those interested in building on this study or investigating related questions that arose throughout the testing phase and final analysis, a list of topics follows:

1. What effect does tpi have on elasticity and resiliency? In the case of the 100% silk and 100% alpaca yarns it seemed that some of the elasticity was due to twist unwinding and allowing the yarn to stretch. This may also be an unexplored dynamic with all the blends.

2. Given that crimp plays a major role in elasticity and resiliency, and in fact, the number of crimps in the yarn, how does the crimp structure of differing breeds affect liveliness? Can a single fleece or breed have differing elasticity due to varying amounts of crimp?

3. Do different types of silk – wild v. cultivated, one wild v. another – produce differing levels of liveliness?

4. Does fibre length affect elasticity? Or only in that longer fibres will introduce a greater number of crimps?

5. How much does fibre preparation affect elasticity? Woolen v. worsted? How do the findings differ from conventional/accepted knowledge?

6. Can there be value in studying rupture points in yarn for the hand spinner? Is there any relationship to elasticity? Can it be quantified and/or described?

7. What effect does elasticity have on calculating angle of twist (AOT) and twists per inch (TPI)? If TPI and/or AOT are altered in some way, is there a way of better understanding the values for the handspinner?
8. What effect does humidity have on elasticity? Can the drying process after wet finishing yarn vis-à-vis elasticity (or take-up) be documented and described? How does washing affect elasticity and resiliency? Does the residue left in the yarn as a result of processing (carding oils, combing solutions, commercial processing liquids/solids) affect the elasticity? Does the weight of those substances enhance or detract from elasticity or resiliency in the dried yarn?

9. Can the liveliness index be improved upon or a new one created that better describes the relationship between elasticity and resiliency for the craftsman?
### Example of Raw Yarn Data

For those interested in how raw data can be documented, an excerpt follows:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Alpaca</th>
<th>Wool</th>
<th>Silk</th>
<th>Weighted Length</th>
<th>Gain</th>
<th>% Gain</th>
<th>1 hr Resiliency</th>
<th>2 sec Resiliency</th>
<th>% Resiliency</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1.1</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#2.1</td>
<td>90</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#3.1</td>
<td>80</td>
<td>20</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#4.1</td>
<td>70</td>
<td>30</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#5.1</td>
<td>60</td>
<td>40</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#6.1</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#7.1</td>
<td>40</td>
<td>60</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#8.1</td>
<td>30</td>
<td>70</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#9.1</td>
<td>20</td>
<td>80</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#10.1</td>
<td>10</td>
<td>90</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#11.1</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#12.1</td>
<td>0</td>
<td>90</td>
<td>2</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#13.1</td>
<td>0</td>
<td>80</td>
<td>4</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#14.1</td>
<td>0</td>
<td>70</td>
<td>6</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
<tr>
<td>#15.1</td>
<td>0</td>
<td>60</td>
<td>8</td>
<td>10</td>
<td>0.75</td>
<td>100%</td>
<td>10.75</td>
<td>10.75</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Table 5 - Sample of Raw Yarn Data (2-ply)*
Appendix C

Partial Catalog of Equipment

Figure 22 – Stress and Measuring Equipment

1 - Triangular Claw Weight Holder
2 - S-hooks
3 - 1.2 lb Knitting Machine Weight
4 - 6” Ruler
5 - Double Point Knitting Needles
Figure 23 - Patrick Green Supercard (Unknown, Supercard)
ELASTICITY AND RESILIENCY
IN HANDSPUN YARNS

Representative Samples

Sample Groups 1-16

Prepared Fiber

Singles

2-ply yarn

3-ply yarn

2-ply Woven Garment Sample

3-ply Woven Garment Sample

2-ply Knitted Garment Sample

3-ply Knitted Garment Sample
# Sample Group 1

**100% Alpaca / 0% Merino Wool**

<table>
<thead>
<tr>
<th>Carded Roving</th>
<th>Singles Continuous Worsted</th>
</tr>
</thead>
</table>

## 2-ply yarn
- Elasticity: 8%
- Resiliency: 100%

**Livellness Index:** +8

## 3-ply yarn
- Elasticity: 8%
- Resiliency: 100%

**Livellness Index:** +8

## 2-ply Woven Garment Sample
- Elasticity: 7%
- Resiliency: 80%

**Livellness Index:** -13

## 3-ply Woven Garment Sample
- Elasticity: 7%
- Resiliency: 50%

**Livellness Index:** -43

## 2-ply Knitted Garment Sample
- Elasticity: 64%
- Resiliency: 80%

**Livellness Index:** +44

## 3-ply Knitted Garment Sample
- Elasticity: 61%
- Resiliency: 85%

**Livellness Index:** 46
Sample Group 1

100% Alpaca
0% Merino Wool
Sample Group 2
90% Alpaca / 10% Merino Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 13%
Resiliency: 100%

Liveliness Index: +13

3-ply yarn
Elasticity: 10%
Resiliency: 88%

Liveliness Index: -3

2-ply Woven
Garment Sample
Elasticity: 13%
Resiliency: 75%

*Liveliness Index: -12

3-ply Woven
Garment Sample
Elasticity: 10%
Resiliency: 67%

*Liveliness Index: -22

2-ply Knitted
Garment Sample
Elasticity: 49%
Resiliency: 100%

*Liveliness Index: +49

3-ply Knitted
Garment Sample
Elasticity: 83%
Resiliency: 88%

*Liveliness Index: +72
Sample Group 2

90% Alpaca
10% Merino Wool
Sample Group 3
80% Alpaca / 20% Merino Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 18%
Resiliency: 93%

Liveliness Index:
+10

3-ply yarn
Elasticity: 18%
Resiliency: 100%

Liveliness Index:
+18

2-ply Woven
Garment Sample
Elasticity: 9%
Resiliency: 100%

*Liveliness Index: +9

3-ply Woven
Garment Sample
Elasticity: 7%
Resiliency: 70%

*Liveliness Index: -23

2-ply Knitted
Garment Sample
Elasticity: 56%
Resiliency: 88%

*Liveliness Index: +45

3-ply Knitted
Garment Sample
Elasticity: 62%
Resiliency: 90%

*Liveliness Index: +52
Sample Group 3

80% Alpaca
20% Merino Wool
Sample Group 4
70% Alpaca / 30% Merino Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 19%
Resiliency: 93%
Liveliness Index: +12

3-ply yarn
Elasticity: 21%
Resiliency: 100%
Liveliness Index: +21

2-ply Woven Garment Sample
Elasticity: 18%
Resiliency: 61%
*Liveliness Index: -21

3-ply Woven Garment Sample
Elasticity: 10%
Resiliency: 100%
*Liveliness Index: +10

2-ply Knitted Garment Sample
Elasticity: 47%
Resiliency: 79%
*Liveliness Index: +26

3-ply Knitted Garment Sample
Elasticity: 58%
Resiliency: 89%
*Liveliness Index: +48
Sample
Group 4

70% Alpaca
30% Merino Wool
# Sample Group 5

60% Alpaca / 40% Merino Wool

<table>
<thead>
<tr>
<th>2-ply yarn</th>
<th>3-ply yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 24%</td>
<td>Elasticity: 19%</td>
</tr>
<tr>
<td>Resiliency: 100%</td>
<td>Resiliency: 93%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +24</td>
<td><strong>Liveliness Index:</strong> +12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Woven Garment Sample</th>
<th>3-ply Woven Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 19%</td>
<td>Elasticity: 11%</td>
</tr>
<tr>
<td>Resiliency: 61%</td>
<td>Resiliency: 34%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> -20</td>
<td><strong>Liveliness Index:</strong> -56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Knitted Garment Sample</th>
<th>3-ply Knitted Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 43%</td>
<td>Elasticity: 63%</td>
</tr>
<tr>
<td>Resiliency: 100%</td>
<td>Resiliency: 85%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +43</td>
<td><strong>Liveliness Index:</strong> +48</td>
</tr>
</tbody>
</table>
Sample
Group 5

60% Alpaca
40% Merino Wool
Sample Group 6
50% Alpaca / 50% Merino Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 25%
Resiliency: 95%

**Liveliness Index:**
+20

3-ply yarn
Elasticity: 33%
Resiliency: 96%

**Liveliness Index:**
+29

2-ply Woven
Garment Sample
Elasticity: 18%
Resiliency: 60%

* **Liveliness Index:** -21

3-ply Woven
Garment Sample
Elasticity: 14%
Resiliency: 49%

* **Liveliness Index:** -37

2-ply Knitted
Garment Sample
Elasticity: 59%
Resiliency: 100%

* **Liveliness Index:** +59

3-ply Knitted
Garment Sample
Elasticity: 62%
Resiliency: 85%

* **Liveliness Index:** +47
Sample
Group 6

50% Alpaca
50% Merino Wool
Sample Group 7
0% Alpaca / 100% Merino Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 35%
Resiliency: 100%

Liveliness Index: +35

3-ply yarn
Elasticity: 31%
Resiliency: 96%

Liveliness Index: +25

2-ply Woven
Garment Sample
Elasticity: 18%
Resiliency: 100%

*Liveliness Index: +18

3-ply Woven
Garment Sample
Elasticity: 18%
Resiliency: 100%

*Liveliness Index: +18

2-ply Knitted
Garment Sample
Elasticity: 64%
Resiliency: 78%

*Liveliness Index: +42

3-ply Knitted
Garment Sample
Elasticity: 84%
Resiliency: 88%

*Liveliness Index: +72
Sample Group 7

0% Alpaca
100% Merino Wool
Sample Group 8

100% Tussah Silk / 0% Cormo Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 5%
Resiliency: 100%

Liveliness Index: +5

3-ply yarn
Elasticity: 4%
Resiliency: 67%

Liveliness Index: -30

2-ply Woven
Garment Sample
Elasticity: 7%
Resiliency: 50%

*Liveliness Index: -43

3-ply Woven
Garment Sample
Elasticity: 3%
Resiliency: 0%

*Liveliness Index: -97

2-ply Knitted
Garment Sample
Elasticity: 38%
Resiliency: 81%

*Liveliness Index: +19

3-ply Knitted
Garment Sample
Elasticity: 83%
Resiliency: 88%

*Liveliness Index: +72
Sample
Group 8

100% Tussah Silk
0% Cormo Wool
# Sample Group 9

90% Tussah Silk / 10% Cormo Wool

<table>
<thead>
<tr>
<th>2-ply yarn</th>
<th>3-ply yarn</th>
</tr>
</thead>
</table>
| Elasticity: 6%  
Resiliency: 80%  
**Liveliness Index:** -14 | Elasticity: 33%  
Resiliency: 96%  
**Liveliness Index:** +5 |

<table>
<thead>
<tr>
<th>2-ply Woven Garment Sample</th>
<th>3-ply Woven Garment Sample</th>
</tr>
</thead>
</table>
| Elasticity: 8%  
Resiliency: 124%  
*Liveliness Index:* +36 | Elasticity: 3%  
Resiliency: 100%  
*Liveliness Index:* +9 |

<table>
<thead>
<tr>
<th>2-ply Knitted Garment Sample</th>
<th>3-ply Knitted Garment Sample</th>
</tr>
</thead>
</table>
| Elasticity: 41%  
Resiliency: 66%  
*Liveliness Index:* +7 | Elasticity: 52%  
Resiliency: 81%  
*Liveliness Index:* +34 |
Sample Group 9

90% Tussah Silk
10% Cormo Wool
Sample Group 10
80% Tussah Silk / 20% Cormo Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 8%
Resiliency: 100%

Liveliness Index: +8

3-ply yarn
Elasticity: 6%
Resiliency: 100%

Liveliness Index: +6

2-ply Woven
Garment Sample
Elasticity: 7%
Resiliency: 100%

*Liveliness Index: +7

3-ply Woven
Garment Sample
Elasticity: 3%
Resiliency: 258%

*Liveliness Index: +224

2-ply Knitted
Garment Sample
Elasticity: 52%
Resiliency: 80%

*Liveliness Index: +32

3-ply Knitted
Garment Sample
Elasticity: 53%
Resiliency: 88%

*Liveliness Index: +41
Sample Group 10

80% Tussah Silk
20% Cormo Wool
Sample Group 11
70% Tussah Silk / 30% Cormo Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 10%
Resiliency: 100%
Liveliness Index: +10

3-ply yarn
Elasticity: 10%
Resiliency: 100%
Liveliness Index: +10

2-ply Woven
Garment Sample
Elasticity: 3%
Resiliency: 100%
*Liveliness Index: +3

3-ply Woven
Garment Sample
Elasticity: 3%
Resiliency: 100%
*Liveliness Index: +3

2-ply Knitted
Garment Sample
Elasticity: 52%
Resiliency: 74%
*Liveliness Index: +26

3-ply Knitted
Garment Sample
Elasticity: 52%
Resiliency: 88%
*Liveliness Index: +40
Sample Group 11

70% Tussah Silk
30% Cormo Wool
Sample Group 12
60% Tussah Silk / 40% Cormo Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 13%
Resiliency: 100%

Liveliness Index: +13

3-ply yarn
Elasticity: 16%
Resiliency: 100%

Liveliness Index: +16

2-ply Woven
Garment Sample
Elasticity: 18%
Resiliency: 81%

*Liveliness Index: -1

3-ply Woven
Garment Sample
Elasticity: 7%
Resiliency: 100%

*Liveliness Index: +7

2-ply Knitted
Garment Sample
Elasticity: 55%
Resiliency: 82%

*Liveliness Index: +37

3-ply Knitted
Garment Sample
Elasticity: 62%
Resiliency: 89%

*Liveliness Index: +52
Sample Group 12

60% Tussah Silk
40% Cormo Wool
### Sample Group 13

**50% Tussah Silk / 50% Cormo Wool**

<table>
<thead>
<tr>
<th>2-ply yarn</th>
<th>3-ply yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 23%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 94%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +20</td>
<td></td>
</tr>
<tr>
<td>Elasticity: 25%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 100%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +25</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Woven Garment Sample</th>
<th>3-ply Woven Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 11%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 67%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> -23</td>
<td></td>
</tr>
<tr>
<td>Elasticity: 7%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 100%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +7</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Knitted Garment Sample</th>
<th>3-ply Knitted Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 43%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 85%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +27</td>
<td></td>
</tr>
<tr>
<td>Elasticity: 63%</td>
<td></td>
</tr>
<tr>
<td>Resiliency: 90%</td>
<td></td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong> +52</td>
<td></td>
</tr>
</tbody>
</table>
Sample
Group 13

50% Tussah Silk
50% Cormo Wool
Sample Group 14
34% Tussah Silk / 66% Cormo Wool

Carded Roving

Singles
Continuous Worsted

2-ply yarn
Elasticity: 24%
Resiliency: 89%

Liveliness Index: +13

3-ply yarn
Elasticity: 21%
Resiliency: 100%

Liveliness Index: +21

2-ply Woven Garment Sample
Elasticity: 18%
Resiliency: 60%

*Liveliness Index: -21

3-ply Woven Garment Sample
Elasticity: 17%
Resiliency: 59%

*Liveliness Index: -24

2-ply Knitted Garment Sample
Elasticity: 50%
Resiliency: 96%

*Liveliness Index: +46

3-ply Knitted Garment Sample
Elasticity: 32%
Resiliency: 117%

*Liveliness Index: +49
Sample Group 14

34% Tussah Silk
66% Cormo Wool
Sample Group 15
17% Tussah Silk / 83% Cormo Wool

Carded Roving

Singles Continuous Worsted

2-ply yarn
Elasticity: 30%
Resiliency: 92%

**Liveliness Index:** +22

3-ply yarn
Elasticity: 33%
Resiliency: 92%

**Liveliness Index:** +25

2-ply Woven Garment Sample
Elasticity: 24%
Resiliency: 100%

{*Liveliness Index: +24

3-ply Woven Garment Sample
Elasticity: 3%
Resiliency: 100%

{*Liveliness Index: +3

2-ply Knitted Garment Sample
Elasticity: 60%
Resiliency: 94%

{*Liveliness Index: +55

3-ply Knitted Garment Sample
Elasticity: 56%
Resiliency: 83%

{*Liveliness Index: +40
Sample Group 15

17% Tussah Silk
83% Cormo Wool
Sample Group 16

0% Tussah Silk / 100% Cormo Wool

<table>
<thead>
<tr>
<th>Carded Roving</th>
<th>Singles Continuous Worsted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-ply yarn</td>
<td>3-ply yarn</td>
</tr>
<tr>
<td>Elasticity: 45%</td>
<td>Elasticity: 43%</td>
</tr>
<tr>
<td>Resiliency: 94%</td>
<td>Resiliency: 94%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong></td>
<td><strong>Liveliness Index:</strong></td>
</tr>
<tr>
<td>+39</td>
<td>+37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Woven Garment Sample</th>
<th>3-ply Woven Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 11%</td>
<td>Elasticity: 3%</td>
</tr>
<tr>
<td>Resiliency: 100%</td>
<td>Resiliency: 100%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong></td>
<td><strong>Liveliness Index:</strong></td>
</tr>
<tr>
<td>+11</td>
<td>+3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2-ply Knitted Garment Sample</th>
<th>3-ply Knitted Garment Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity: 72%</td>
<td>Elasticity: 64%</td>
</tr>
<tr>
<td>Resiliency: 95%</td>
<td>Resiliency: 95%</td>
</tr>
<tr>
<td><strong>Liveliness Index:</strong></td>
<td><strong>Liveliness Index:</strong></td>
</tr>
<tr>
<td>+67</td>
<td>+59</td>
</tr>
</tbody>
</table>
Sample Group 16

0% Tussah Silk
100% Merino Wool