Investigating the factors affecting tensile strength of human hair

Planning: (Skill A)

Hypothesis

There will be a difference in tensile strength in blonde hair and black hair of similar thickness. Blonde hair will have a higher tensile strength than black hair when at similar thickness. Blonde hair has more sulphur-sulphur covalent bonds than black hair. Hair contains the protein keratin, which contains a large proportion of cysteine with S-S bonds. The disulphide bond is one of the strongest bonds known anywhere in nature. The cross-linking by disulphide linkages between the keratin chains accounts for much of the strength of hair. Blonde hair has more of these bonds therefore blonde hair will have a higher tensile strength and elasticity levels.

Null Hypothesis

There will be no difference in tensile strength between black hair and blonde hair of similar thickness. Blonde hair having more sulphide bridges will not mean that blonde hair has a higher tensile strength than black hair.

Background Knowledge

Hair has a very high tensile strength. It can hold up 60kg of weight before breaking. This high strength is due to its structure.

Hair is made of the fibrous protein keratin. Figure 1 shows keratin molecules are made up of three helices. They are held together by strong covalent bonds called sulphur bonds. Eleven of these molecules group together to form a micro fibril. Then, hundreds of micro fibrils join together to form a single hair.

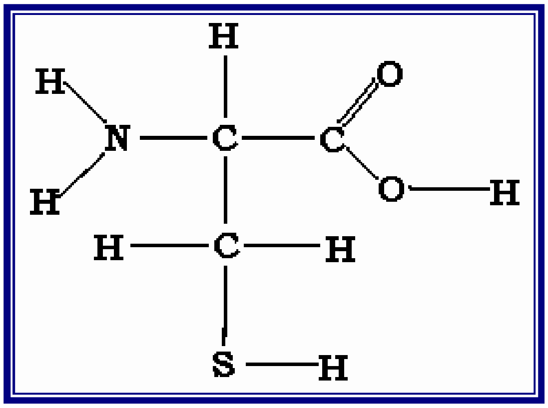
Figure 1: The structure of a hair

Hair is made of cells called epithelial cells which are arranged in three layers. The inner most layer is the medulla, the middle layer is the cortex and the out layer is the cuticle. The medulla is mainly soft keratin and the cortex and cuticle are mainly hard keratin.

This structure has great strength. The cuticle, the outermost layer, is where you find a lot of the protein keratin. The cortex is the thickest middle layer, providing strength and defining colour of hair. The cortex also gives the hair its elasticity and flexibility. The medulla, central core, gives hair its strength and breadth.

The structure of keratin is maintained by numerous sulphur to sulphur covalent bonds. Keratin contains high concentrations of the amino acid cysteine.

Figure 2: The amino acid Cysteine



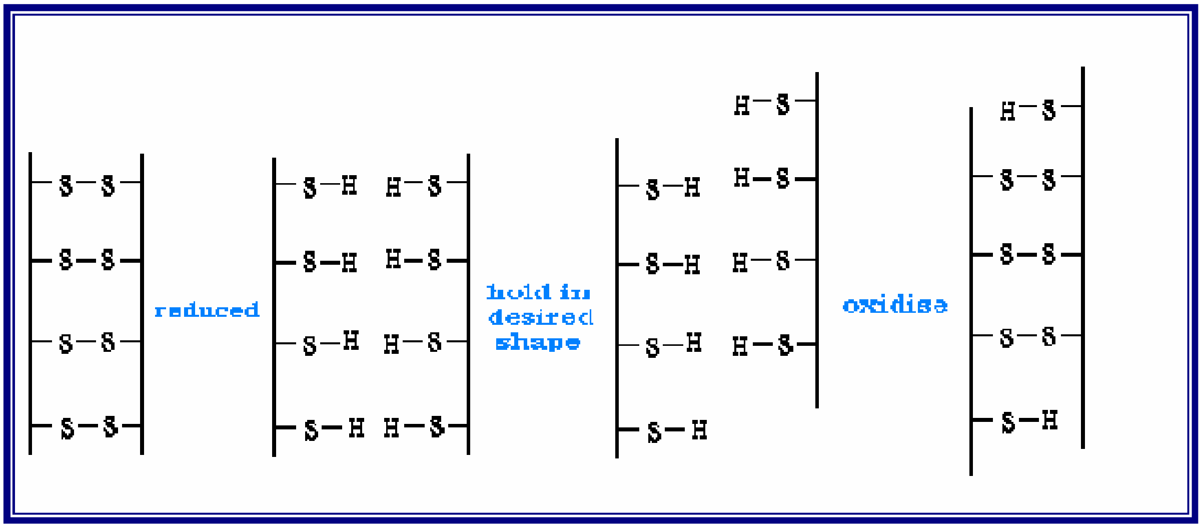
Every Cystine unit contains two cysteine amino acids in different chains which have come to lie near to each other and are linked together by two Sulphur atoms, forming a very strong chemical bond known as a disulphide bridge. Many disulphide bonds form down the length of the keratin chains, joining them together like the rungs of a ladder. The disulphide bond is one of the strongest bonds known anywhere in nature. This cross-linking by disulphide linkages between the keratin chains accounts for much of the strength of hair. A suitable amount of Sulphur Bridge is important in enhancing the elasticity of hair due to the strength of the disulphide bond.

Within each hair bonds of a different kind, called hydrogen bonds also link the keratin chains. There are far more hydrogen bonds than disulphide linkages. The hydrogen bonds are much weaker than the disulphide linkages and more easily broken, and give hair its flexibility. Hydrogen bonds are broken apart when the hair is wetted, and form again when the hair dries.

Hair used for the investigation must not be 'damaged' in any way, i.e; should not be dyed/coloured, permed, straightened, etc. The hair also must not be curly. I will be only looking at naturally straight hair for this investigation.

Permed and dyed hair cause severe damage to hair by reducing and breaking disulphide bonds between protein amino acids (which keep the hair strong) and they change the chemistry of hair by altering the protein rich internal structure of the fibre. In perming, a mild reducing agent is used to break the sulphur bonds. The helices are unwound and the hair is styled. A gentle oxidising agent (usually hydrogen peroxide) is treated to the hair to make the sulphur bonds reform. This results in a 'permanent wave'. (Figure 3 shows the breaking and reforming of sulphur-sulphur bridges can produce permanent changes in the shape of protein molecules). Permed hair has only 90% of the original disulphide bonds, which leaves hair weaker than before it was permed.

Figure 3: Breaking and reforming S-S bridges



Heat (like from hair straighteners) disrupts the structural bonds (particularly weak Hydrogen bonds) enough to give hairs wounded around a roller some temporary curly aspect. However, this effect can be easily abolished by an increase in humidi ty or contact with water. Longer lasting permanents use chemicals such as thioglycolic acid to disrupt the disulphide bonds.

Hairs to be tested with should not have their disulphide bonds damaged/broken or our hypothesis will become invalid even before t he investigation takes place.

Variables

To Control…(keep the same)	To investigate…(measuring/changing)
<u>Hair MUST NOT be:</u> co loured/dyed straightened (by applying heat) permed (by applying heat) curly (naturally) from the same person	Tensile Strength (masses applied on hair) Thickness of hair/colour of hair
<u>Hair MUST be:</u> black or blonde straight (naturally) from the same age group	

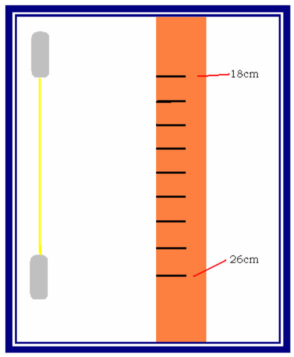
Equipment

2 X Clamp stand – to hold everything upright
2 X Clamp – to hold paperclip/hair and ruler
100cm ruler – to measure how far hair stretches before it breaks (tensile strength)
2 X paperclip – to hold hair and mass
10kg masses with holder – to put tension on hair
Selotape – to hold loop of hair in paperclip
15 pieces of black hair – to compare
15 pieces of blonde hair – to compare
Micrometer – to measure hair thickness

Method

1. I will first take five pieces of hair randomly from six different people. Three of these people should have black hair and three should have blonde hair. My total numbers of hair should be fifteen black and fifteen blonde. Hair samples should be taken from six different people to make sure that a fair and accurate test takes place. For example if all fifteen black hairs were taken from the same person, it could just mean that that person had thicker hair than normal thickness of black hair. This would make my results invalid. I will take all hairs from the same age group (my age group, 17-18), to erase the 'age of hair follicle' variable when comparing its tensile strength.
2. I will set up the micrometer to measure each hair thickness by placing hair under lens and measuring its thickness using a shown scale. I will record each thickness in an appropriate table.
3. I will place a black hair and a blonde hair of similar thickness side by side. This will be done to compare tensile strength of hairs of similar thickness.
4. Equipment will be set up as shown in Figure 5, (below) to start investigation. The hair will be carefully put in. The meter rule should be touching the bottom of the clamp stand with 0cm at the top and 100cm at the bottom. I need to make sure the hair can not slip out of the paperclip from the bottom or the top. Everything must be secure. The length of the loop of hair formed should be similar as with all hairs being tested. The weight should not be added until the rest of the equipment has been set up accurately.
5. Once the hair is set up in with the equipment, I will measure how far down the hair is on the meter rule. (Look at Figure 4, for assistance). I will recor d this reading in a table similar to Table 1.

Figure 4: Measuring hair lengths



6. A mass of 10kg will be placed on the paperclip at the bottom only after first measurements have been taken.
7. I will add the masses slowly so when the hair breaks I have a better view of the length of the hair.
8. When I see the hair break I will record its maximum length in my table and the weight in kg applied on hair at that point, when it reached its maximum elasticity.
9. I will repeat this whole process for all the blonde hairs and the black hairs. I will do the hairs of similar thickness after one another. For example; a blonde hair of thickness *x* would be measured first than a black hair of thickness *x* would be measured.

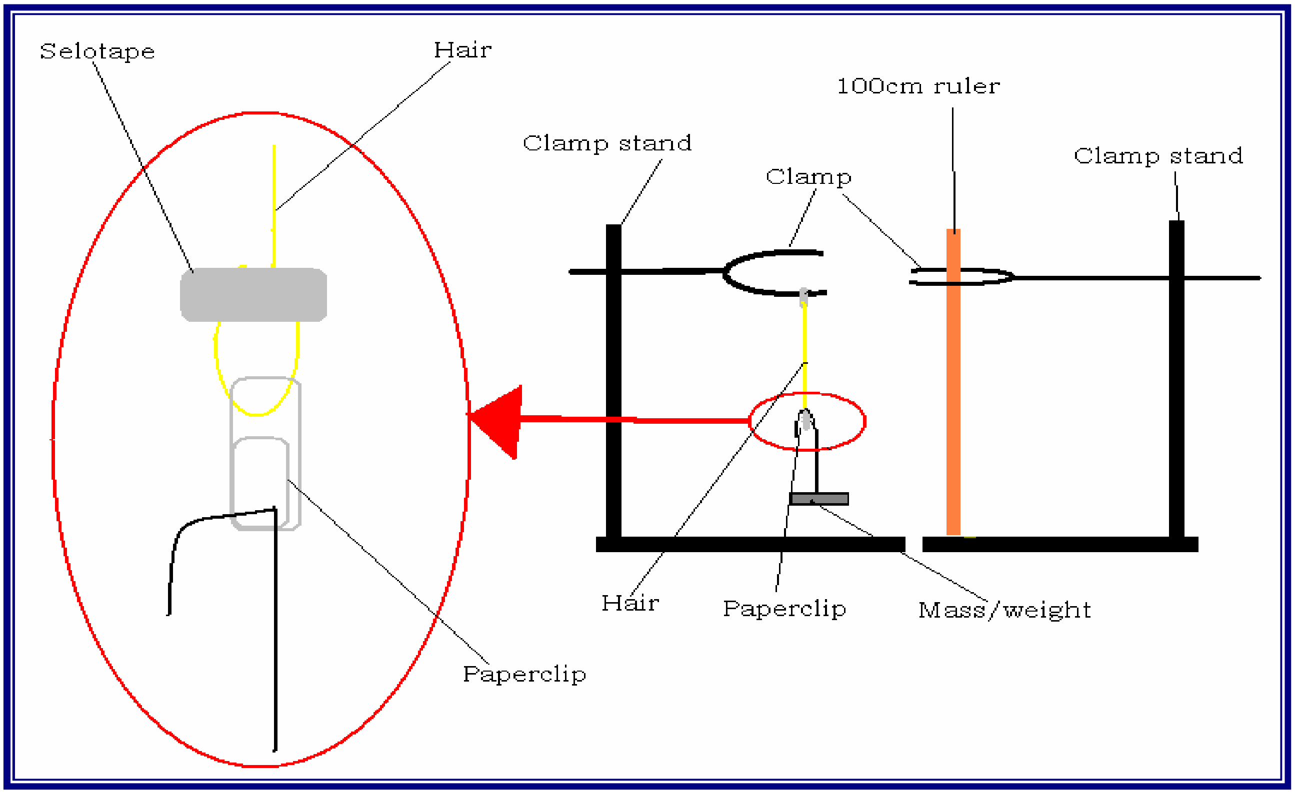
There will be six people in my group including me. Each person will test five hairs each.

Table 1: Example of results table

Hair no.	**B1**	**B1**	**B2**	**B2**	**B**	**B**	**B**	**B**
	length bfr W app		length bfr breaking		length stretched bfr breaking		max W app bfr breaking	

	(cm)		(cm)		(cm) **2** minus **1**		(kg)	
1								
2								
.								
.								

Figure 5: Labelled diagram of the equipment set up



Statistical Test

I will use the t-test because I am looking for a difference of tensile strength in black and blonde hair. I will be using actual measurements (e.g. weights), and will have a large data set (30 pairs of data). I am comparing two sets of data.

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Implementing: (Skill B)

Modifications

- Four different colours of hair need to be used; to increase range of results and to make my conclusion more reliable.
  Ginger, Blonde, Black and Brown hairs will be used.

- 30 strands of hair will be used for each colour. 5 hairs from 6 people for each colour will be taken.

- An eyepiece graticule will be used to measure hair thickness. Similar thickness of hairs will be compared.

- Girls' hair will be used. There are two reasons for this:
  a) Girls have longer hair
  b) Hormones may affect hair strength. Girls and boys may have different hormones.

- There should be a 10cm (100 mm) gap between each paperclip. (Figure 5).

- A 10g weight must be used each time.

- I will need to modify my Hypothesis and Null Hypothesis because instead of comparing just two colours of hair I am now comparing four different colours of hair.

  Hypothesis:
  There will be a difference in tensile strength between brown, blond, ginger and black hairs of similar thickness. Blonde hair (lighter coloured hairs) has more sulphur-sulphur covalent bonds than black hair (dark coloured hairs). Hair contains the protein keratin, which contains a large proportion of cysteine with S-S bonds. The disulphide bond is one of the strongest bonds known anywhere in nature. The cross-linking by disulphide linkages between the keratin chains accounts for much of the strength of hair. Lighter coloured hair has more of these bonds therefore lighter coloured hair will have a higher tensile strength and elasticity levels.

  Null Hypothesis:
  There will be no difference in tensile strength between brown, blonde, ginger and black hair of similar thickness. Lighter coloured hairs having more sulphide bridges will not mean that lighter coloured hairs have a higher tensile strength then dark coloured hair.

- Now that I am not comparing just two sets of data I can no longer do the T-Test. I am comparing four sets of data. My data will be categorical. There is a simple statistical test which looks at the difference between *observed* and *expected* values and relates them to a probability level, thus making it possible to identify how likely it is that the values are significantly different. This test is called the *Chi squared test.*

Precautions to ensure reliability

- We are assuming ethnic background does not affect our results. It will not cause a massive variation in our conclusion.
- All hair samples must be taken from 16-18 year old females.
- 6 different samples must be taken for each colour of hair.
- Make sure all equipment is set up; ensuring the strand of hair is fastened to the shown equipment correctly. (Figure 5).
- Each hair is tested five times, so I am repeating the experiment, to make my results reliable and more accurate.

Results

(My own (raw data) results will be highlighted in dark red on tables 2, 3, 4 & 5).

(The letter 'B' is used in my results to show where the hair broke).

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Analysing: (Skill C)

Calculations

Strength is determined by the amount of stress a hair can withstand without breaking. To work out the strength of each hair I calculated the stress applied to each when breaking. To do all the calculations I used the following formulas:

1. **Force (N) = Mass (g) X 0.001 X 9.8**

   E.g. 10 x 0.001 x 9.8 = Force (N)
   Force = 0.098N

2. **Cross Sectional Area (μm^2) = πr^2**

   E.g. 3.14 x 26 x 26 = Cross Sectional Area (μm^2)

Cross Sectional Area = 2122.64μm^2

3. Stress (Nm^{-2}) = Force (N) / (Cross Sectional Area (μm^2)/1000000)

E.g. 0.098 / (2122.64/1000000) = Stress
Stress = 46.16892172 (Nm^{-2})

4. Strain = Extension (mm) / Original Length (mm)

E.g. 32 / 100 = Strain
Strain = 0.32

The tables on pages 14 to 36 show how I calculated my values to do the statistical test.

Discussion

Melanin molecules are proteins, which are produced at the root of each hair. The more melanin in your hair, the darker it will get. An amino acid called tyrosine is converted into melanin so the hair will have colour. First, the body's blood vessels carry tyrosine to the bottom of each hair follicle. Then, in this 'melanin factory' tyrosine is used as the raw material for the production of the natural melanin that is the colour in hair. In short, natural hair colour depends upon the presence, amount and distribution of melanin, a natural pigment found in the cortex.

All natural hair colours are created from two types of melanin.
Eumelanin = black pigment
Pheomelanin = red/yellow pigment
Mixed melanin's = when both eumelanin and pheomelanin mix together inside one melanin granule.

The natural colour of the hair is decided by:

a) What type of melanin is in the hair
b) How much melanin is in the hair
c) How closely packed or scattered the melanin is within the cortex.

The type of melanin and the size of the granules determine whether hair will be brown, blonde, ginger or black. The amount of melanin and its distribution determine how dark or light the hair colour will be.

Black hair is created from granules full of eumelanin densely packed in the hair's cortex.

Brown hair, depending on its cool or warm tones and its darkness or lightness, is created either from granules filled with eumelanin and more sparsely distributed along the cortex than those of black hair, or granules filled with a blend of mixed melanin's. The red/yellow pheomelanin is believed to cause the warm, golden, or auburn tones found in most brown hair.

Blonde hair has a very low melanin content. And while scientists have not yet determined which is dominant, it is believed that eumelanin creates blonde hair. Melanin in blonde hair is so sparse that what we actually see is the colour of the hair fibre itself, keratin, which is a pale yellow, off-white shade.

Granules filled with pheomelanin create Ginger hair. The pheomelanin in ginger hair is less densely packed in its granules. Its shape is somewhat more irregular than its black counterpart, eumelanin. It is slightly rounder and more spread out.

From my results I found out that brown hair needed the greatest amount of force to break. Blonde hair needed the least amount of force to break. Black hair was second strongest and ginger hair was third strongest. The order of strength (from my results) of hair is as follows: Brown, Black, Ginger, and then Blonde.

Brown hair stretched the most before breaking. Blonde hair stretched the least before breaking. Black hair stretched the second furthest and ginger hair stretched the third furthest. The order of length of hair stretched (from my results) before breaking is as follows: Brown, Black, Ginger, and then Blonde.

Brown hair experienced the highest strain before breaking and blonde hair experienced the lowest strain before breaking. The order of strain experienced by hair (from my results) before breaking is as follows: Brown, Black, Ginger, and then Blonde.

Brown hair experienced the highest tensile stress value before breaking and blonde experienced the lowest tensile stress value before breaking. The order of tensile stress experienced by hair (from my results) before breaking is as follows: Brown, Ginger, Black, and then Blonde.

Graph 1 shows the average force required to break the four colours of hair. From this graph I can see that brown hair required the greatest force to break. Black hair also required a large amount of force to break and so did ginger hair. Black hair only required a small amount of more force to break then ginger hair. The breaking force required for brown, black and ginger hair was quite similar. Blonde hair required much less force to break compared to the other colours of hair. This proves that the disulphide bonds in the blonde hair are not a big advantage for strength of the hair. The darker the hair the stronger the force required for the bonds in the hair to break. The darker the hair the more resistant it is to breaking when forces are applied. The darker the hair the higher concentrations of melanin present along the hair cortex.

The same sort of pattern is seen in graphs 2, 3, 4 and 5. Graphs 2, 3, 4 and 5 show the extension of hair when masses are added. Blonde hair breaks the earliest and brown hair breaks the latest.

Graph 2 shows brown hair. Brown hair requires about 120g to extend up to about 70mm before breaking. The graph follows a basic trend and there are no anomalous results. All results fit the line of best fit.

Graph 3 shows blonde hair. Blonde hair requires about 80g to extend up to about 35mm before breaking. The graph follows the basic trend and most results fit the line of best fit. There is one anomaly, though. The extension should not increase and then decrease. It should keep on decreasing. There must have been an error in recording this result. The results in graphs 2, 3, 4 and 5 are all averages. To work out the blonde values in table 32, the results in tables 12, 13, 14, 15, 16 and 17 were used. There was only one value for the extension at 80g, in table 15. This value was smaller than the average of all the extensions in all six tables. This sample of hair should have broken at 80g not 90g. This did not happen. This may have been an error in not measuring correctly.

Graph 4 shows ginger hair. Ginger hair requires about 100g to extend up to about 60mm before breaking. The graph follows the basic trend until it gets to 55g point. From this point onwards the hair length increases and decreases dramatically. This should not happen. The reason why this happens is described above with the blonde hair. It is an error in measuring.

Graph 5 shows black hair. Black hair requires about 140g to extend up to about 65mm before breaking. This graph is perfect. There are no anomalies. All points meet the line of best fit accurately.

Graph 6 shows the average stresses and strains experienced by each hair colour. All four hair colours are plotted on the same graph so they can be easily compared against each other. Brown, blonde and ginger hairs do not follow the normal trend. The stresses and strains for these three should continue to increase. Tables 57, 58, 59 and 60 show where the stress and strain values came form. The results are like this because when the stress and strain values were calculated the average extensions were used, which had a few faults, as describe above.

Graphs 7, 8, 9 and 10 show clearly what is happening to the stress-strain curves. Graph 7 shows one anomalous result. It has a high stress and strain value. Graph 8 also shows only one anomalous result. These two graphs show the basic trend. Graph 9 shows the normal trend until the stress value gets to 150Nm^{-2}. Then it decreases and goes back on itself. This should not happen. The reason for this is explained above. There is an error in the extension averages. Graph 10 shows no anomalies.

Graphs 11, 12, 13 and 14 show modified values for stress and strain in all colours of hair. Graph 11 shows the modified stresses and strains for brown hair. This graph does not bend backwards and the stress and strain values do not decrease. Graph 12 shows the modified stresses and strains for blonde hair. This graph does not show values of stress and strain decreasing. Graph 13 shows the modified stresses and strains for ginger hair. This graph has changed a lot. It reads much clearer. Stress and strain increases throughout. This is exactly what the graph should look like. Graph 14 is the same as graph 10. It did not need any modifications.

The toughness of a hair is measured of its resistance to break. A lot of energy is required to break a tough material. Finally, the strength of a material (or 'tensile strength') is the greatest tensile stress it can undergo before breaking.

Hair is an elastic material; it can stretch to a certain maximum point (elastic point) before breaking. The largest tensile stress that can be applied to a material before it breaks is known as its ultimate tensile stress (UTS). This value is sometimes referred to as the materials breaking stress.

Graph 7 shows the stress-strain points for brown hair. Graph 11 shows a modified version of this. The UTS for brown hair is 359.03. Graph 8 shows stress-strain points for blonde hair. Graph 12 shows a modified version of this. The UTS for blonde hair is 125.48. Graph 9 shows the stress-strain for ginger hair. Graph 13 shows a modified version of this. The UTS for ginger hair is 286.58. Graph 10 shows the stress-strain points for black hair. Graph 14 shows a modified version of this. The UTS for black hair is 158.31.

Overall I can see that brown hair was the strongest. This was not expected. I expected black hair to have the highest tensile strength, as it had a higher density of melanin along the cortex. Blonde hair turned out to be the one with the lowest tensile stress. Ginger haired people have a high density of the pheomelanin pigments in their hair fibre. Those who produce virtually no eumelanin have a red to orange colour depending on the density of the pigment in the hair fibre. Red haired people who have a greater relative proportion of eumelanin production have a deeper red to red brown colour. Ginger hair also should have a high tensile strength. This is what I saw in my results. Black hair should also have a high tensile strength. My results showed black hair to have high tensile strength but not the highest.

There are other ways in which hair tensile strength could have been measured. Hair products like shampoos have an effect on hair tensile strength. They are now designed to change hair strengths. Different makes of hair shampoos could be used. Strength could be measured in a similar way to how I measured it. A control will be also be needed, with hair with no products added.

These modifications in Graphs 11, 12, 13 and 14 show what the stress strain graphs should look like. In Graphs 7, 8, 9 and 10 the
lines should not bend backwards.

Statistical Test

I will be using the (Chi squared test) X^2.

The formula for the Chi squared test is as follows:

$$X^2 = \sum \left[(O - E)^2 / E\right]$$

O = Observed value
E = Expected value

The ((O – E) ²) part of the formula considers the size of the difference between the observed and expected values. This difference could be either positive or negative. To avoid the mathematical problems associated with negative values, the difference is squared.

The (E) part of the formula relates the size of the difference to the magnitude of the numbers involved.

The sigma (∑) 'sum' symbol is required because there is not just one pair of observed and expected values, but several (in this case four).

By taking all the observed values of stress from tables 57, 58, 59 and 60, I can work out the expected value for each hair colour.

I can then place these values in a table and work out the value for X^2, using the chi squared formula.

$E = (O_{Brown} + O_{Blonde} + O_{Ginger} + O_{Black}) / 4$
$E = (297.3 + 121.5 + 246.7 + 158.3) / 4$
$E = 205.95$

	Brown	**Blonde**	**Ginger**	**Black**
O	297.3	121.5	246.7	158.3
E	205.95	205.95	205.95	205.95
(O - E)	91.35	-84.45	40.75	-47.65
(O - E)²	8345	7132	1661	2271
((O - E)²) / E	40.519	34.629	8.063	11.025

$X^2 = 40.519 + 34.629 + 8.063 + 11.025$
$\mathbf{X^2 = 94.235}$

To calculate the degrees of freedom to be used can be found as follows:

- Number of categories minus 1.

In this case: 4 – 1 = **3**

The critical value (taken from critical values for the Chi squared test) at **3** degrees of freedom is **7.81** (at the 5% level).

The test statistic ($X^2 = 94.235$) is greater than the critical value
(C.V = 7.81, at the 5% significance level). We therefore can reject the null hypothesis and state there is a significant difference between the observed a

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Evaluating: (Skill D)

Limitations

- The selotape holding hairs in the paperclip at the top and at the bottom could have interfered with the tertiary structure of the protein, keratin. This could have increased or decreased the bond attractions in the hair to cause the hair to have a high or low tensile stress. This would make my results unreliable. The hairs showing higher tensile stress may just be showing how sticky the selotape is and how strongly it is holding the hair structure together. This though, would affect all my results, as all hair samples had selotape on them to hold them together at the top and at the bottom. So, this limitation would affect all hairs making it a very weak limitation. My conclusion will not be affected as this limitation affects all hairs.

- The time in between weights were added is another limitation. When each weight was added the hair stretched. But when there were a lot of weights on hair, the hair stretched quickly and then the length was measured. After I finished measuring the hair had slowly stretched a little bit more. So the measurement was wrong. When the next weight was added extra extension was added onto the new extension. My results were affected by this because some extensions were false making some data imprecise. Therefore, my conclusion will be invalid, because some hair samples could have broken at lower weights if I had waited for the hair to stretch, very slowly until it broke. There needed to be a time limit in which I had to record the extension of the hair, before adding the next weight to the hair.

- The eye piece graticule can be a limiting factor. Different people measured hair thickness and recorded it to what they felt the thickness ought to be according to the scale. It was not very clear to see how thick the hair was, as the hair was faded under the microscope at all magnifications and the outline was difficult to see. This could affect my results as the thickness of hairs was used to calculate the cross sectional area of the hairs, which was then used to calculate the tensile stress experienced by the hair. This could make my tensile stress values incorrect. My conclusion therefore could be affected; by making out that a certain coloured hair had a higher tensile stress than another coloured hair, when really it shouldn't have. This would make my conclusion unreliable.

- There were different shades of hair colour, for example, there were light brown hair colours and dark brown hair colours. It was sometimes hard to distinguish between brown and blonde. This was the same for blonde hair. This would have an affect on the reliability and precision of my results making the accuracy of the strengths of different colours of colours of hair inaccurate. There should have been a certain shade of colour of hair (same amount of melanin in each brown hair) used for each colour sample. My conclusion will be imprecise because brown or blonde hair shades could cause incorrect results and make my conclusion incorrect.

- The 10g mass is a limitation as the hair could break at lower masses than they actually did, for example a hair that broke at 50g could have broken at 41g, but I wouldn't know that as I only used 10g masses. So, I got false readings implying the hair is stronger than it actually is. If smaller masses were used my results would be much more accurate to make my conclusion reliable. This limitation could cause my conclusion to be invalid, causing the hairs strength and point on breaking higher or lower than it actually is.

Conclusion

After doing my statistical test I can reject my null hypothesis and accept my hypothesis and say that brown, blonde, ginger and black hairs differ in tensile strength. I have proved this difference in my calculations, mainly in graphs 1 and 6. From my results I can see that darker coloured has a higher tensile stress compared to lighter coloured hairs. In my hypothesis I said that lighter coloured hair would have a higher tensile strength than darker coloured hair, due to lighter coloured hair having sulphur-sulphide bonds, which are very strong. I have disproved this. Through testing all four colours of hair I can see that these strong sulphur bonds do not reflect any tensile strength qualities. Lighter coloured hair does not have an advantage over dark coloured hair when it comes to tensile strength. It mainly depends on the type of melanin the hair contains. The denser the melanin quantity is the stronger the hair.