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Influence of water hardness on the use of hair care products in the sensory evaluation and physical properties of hair

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ABSTRACT

In this study, the effects of water hardness on the use of hair care products is analysed on the basis of sensory assessments and physical characteristics of hair. The study is divided into sections on sensory attributes and physical properties to assist with a scientific analysis of the influence of water hardness on the use of hair care products. Sensory evaluation is conducted by a trained shampoo panel with 8-10 members. In order to carry out an objective assessment of sensory properties, physical measurement techniques are used that focus on quantifying the combing force of the hair. Three shampoo technologies (standard shampoo, polymer care technology, silicone technology) are applied on damaged hair and undamaged hair. This study shows that water hardness has significant influence on the use of these three shampoo technologies. Water hardness has a significant effect on eight attributes of the shampoo panel: Perceived hair quantity, aqueous foam, rinsing time in seconds, ease of disentangling, combability, residual product, hair - dullness, lack luster, hair - softness. Silicone technology shows best performance regarding water hardness.

Keywords: *Water Hardness, Hair Care Products, Sensory Evaluation, Combing Force*

1. INTRODUCTION

Hair wash is the most commonly way of hair treatment. Until market launch of non-alkaline hair shampoo in 1933 only soap was used for hair wash (1). Requirements regarding shampoos exceed function of cleansing. A shampoo should improve hair quality and satisfy different hair qualities, age groups and individual washing habits. Not too strong degreasing, skin tolerability, good mucosa tolerance, chemical and physical stability, conditioning effects as well as foaming power is expected from a shampoo (2).

Water hardness is particularly interesting for detergents. Hard water with a high proportion of lime can lead to limescale in washing machines and on clothing (3). Calcium and magnesium ions are the most prevalent and give water hardness (4).“

Consumers regard water hardness in direct connection with health and beauty of hair. A frequently observed phenomenon is that hard water contributes to blunt and dull hair. In the market there are products which advertise with an anti lime effect for example „Schauma“. Expectation of these shampoos is that they perform well at any water hardness (5, 6, 7).

In this study influence of water hardness on the use of hair care products is investigated. Different shampoo technologies are tested by the application of sensory evaluation at different water hardness. To increase objectivity of this study physical measurements (combing force) are applied on hair.

In detail, following questions are researched:
- Does the time for which the hair is soaked affect combing forces? (1 min. vs. 15 min.)
- How do different shampoo technologies behave in relation to water hardness?
- How does the degree of hair damage in combination with water hardness affect combing forces in wet hair?
- Which attributes depend on water hardness? On which attributes does water hardness have a significant effect?

2. MATERIALS AND METHODS

In this study, the effects of water hardness on the use of hair care products are analysed on the basis of sensory assessments and physical characteristics of hair. The thesis is divided into sections on sensory attributes and physical properties to assist with a scientific analysis of the influence of water hardness on the use of hair care products. Sensory evaluation was conducted by a trained shampoo panel with 8-10 members. In order to carry out an objective assessment of sensory properties, physical measurement techniques were used that focussed on quantifying the combing force of the hair.

Hair

For this study damaged and undamaged Caucasian scalp hair is used. Hair material is purchased from Kerlin International Haarfabrik GmbH (Backnang, Germany). For this study two different degree of damage is used for hair. 1. undamaged hair and 2. damaged hair (Kerling bleach). Undamaged hair is taken from hair of different humans. Damaged hair is bleached in 2 % hydrogen peroxide solution. Length of hair is 23 cm and bundled with bond braids.

Physical measurement (combing force) is accomplished with damaged and undamaged hair with width of 2 cm and weight of 2 g. Sensory evaluation is carried out with only damaged hair with width of 2,8 cm and weight of 10g. Hair material is taken from one charge. Physical measurement and sensory evaluation is carried out with soft water (0 ° dH, 3 ° dH) and hard water (15 ° dH). Due to technical difficulties water hardness could not be adjusted below 3 ° dH for sensory evaluation. Therefore, for soft water, water hardness of 0 ° dH was applied for combing force and 3 ° dH for sensory evaluation. Temperature of water is 37 °C.

Shampoo

Three different shampoo technologies are used - standard shampoo without care, polymer care technology and silicone technology. Standard shampoo consists of tenside Sodium Laureth Sulfate, polymer care technology is silicone free and consists of tenside system Sodium Laureth Sulfate und Cocamidopropyl Betaine. Polymers are Polyquaternium-7 (PQ-7) und Polyquaternium-10 (PQ-10). Silicone formula contains tenside system Sodium Laureth Sulfate und Cocamidopropyl Betaine. Polymers are Guar Hydroxypropyltrimonium Chloride (Jaguar C 17) and Guar Hydroxypropyltrimonium Chloride (Jaguar C14S). Silicone is Dimethicone. pH value is adjusted to protective acid mantel, 4,8-5,2.

Combing force

Combing force measures force which need to be applied when combing hair. A universal testing machine is applied. Combing force is measured on wet hair. Aim of this measurement is to investigate if water hardness (0 ° dH and 15 ° dH) and standard shampoo without care, polymer care technology and silicon technology has a significant influence of combing force of damaged hair as well as undamaged hair.

Accomplishment

Hair is soaked in water (0 ° dH and 15 ° dH) for 1 minute as well as 15 minutes. For treatment with shampoo technologies new hair strand is applied in each case. After extraction from water, water is stripped twice from hair strands. For preparation, hair is washed with a standard shampoo. 0,4 ml standard shampoo is massaged on hair for 1 minute, another 1 minute impacted on and 2 minutes stripped and combed under running water. Hair is dried at 22 +/- 1 °C and relative humidity of 55 +/- 5 % for 5 days. Subsequently combing force is measured after application of polymer care technology and silicone technology. Therefore, treated hair with standard shampoo are soaked for 1 minute and 15 minutes in each water hardness (0 ° dH and 15 ° dH). Procedure of application of polymer care technology and silicone technology is the same as for standard shampoo. For each shampoo 10 measurements are applied. Furthermore, wet weight of hair strands is justified.

Statistical Evaluation

Before determination of combing force null hypothesis and alternative hypothesis is formulated:

H_1 = Mean values of combing force of hair strands which were treated with 15 ° dH differ significantly from mean values of combing force of hair strands treated with 0 ° dH.

H_0 = Mean values of combing force of hair strands which were treated with 15 ° dH do not differ significantly from mean values of combing force of hair strands treated with 0 ° dH.

For significance assessment t-test is applied with significance level of 5 %. Shapiro Wilks test is applied to prove if normal distribution is present. To test if variances of population is homogeneous Levene test is used. Statistical evaluation is carried out with software SPSS.

Sensory Evaluation

Hair shampoo technologies are evaluated by a trained shampoo panel (8-10 members) based on Spectrum™- method. Panelists are trained on shampoo attributes which are constantly reviewed. Temperature in panel room is 22°C +/- 1°C and humidity is 45 %.
Following table provides an overview of shampoo technologies (A, B, C), standard products, both water hardness (3 ° dH, 15 ° dH) and hair number. Aim of this study plan is to test each product with each possible product combination by panel. Not all mentioned shampoo products in table 1 are available on the market anymore.

Table 1: experimental plan for sensory evaluation

Shampoo	Standard product	Water hardness (° dH)	Strand number
A C	Dove Therapy Hell Nivea Beauty Care	3	1

B A	Schwarzkopf Gliss Kur Dove Therapy Hell	3	2
A B	Nivea Strong Power Schwarzkopf Gliss Kur	15	3
B C	Nivea Strong Power Nivea Beauty Care	3	1
C A	Schwarzkopf Gliss Kur Nivea Beauty Care	15	3
C B	Dove Therapy Hell Schwarzkopf Gliss Kur	15	3

Sensory evaluation is only carried out with damaged hair compared to measurement of combing force carried out with damaged and undamaged hair. Damaged hair strands are from the same charge. Damaged hair strands are rotated so that each product is assessed on each strand. Sensory evaluation is carried out by 8 to 10 trained panelists. Three panel sessions are conducted for both water hardness (3 ° dH, 15 ° dH). Thereof, multiple determination with 36 to 40 individual values follow. Standard products are announced at water hardness 15 ° dH. For preparation, hair strands are cleansed with standard shampoo. It's the same procedure than preparation of hair strands for combing force. 2,0 ml is applied to hair strands, massaged, acted on for 1 minute and rinsed off under water. Finally, hair strands are combed. Hair strands are dried at temperature of 22 °C +/- 1 °C and humidity of 45 %. Before sensory evaluation hair strands are soaked in each water hardness (3 ° dH, 15 ° dH). Panelists assess following attributes: hair structure, flow properties, sensory and ropy, residual product, distributability in hair strand, foaming, foaming speed, perceived hair quantity, foam bubble distribution, foam sensory, foam quantity, foam aging, rinsing time in seconds, sliding ability at rinsing, rinsing time, ease of untangling, combability, sliding ability and sensory.

Statistical Evaluation
Before sensory evaluation is carried out null hypothesis and alternative hypothesis is formulated:

H_1 = Mean values of attributes assessed at 15 ° dH differ significantly from mean values of attributes assessed at 0 ° dH.

H_0 = Mean values of attributes assessed at 15 ° dH do not differ significantly from mean values of attributes assessed at 0 ° dH.

For significance assessment ANOVA is applied with significance level of 5 %. Effect of water hardness, product and interaction of each attribute is investigated. Effect of water hardness investigates if the shampoo technologies (standard shampoo without care, polymer care technology, silicone technology) at 3 ° dH act significantly differently to water hardness 15 ° dH. Product effect investigates if there is a significant difference of shampoo technologies at 3 ° dH and 15 ° dH. Interaction effect proofs if shampoo technologies show a significant opposite behavior in both water hardness.

Post hoc tests (Bonferroni and LSD - Least Significant Difference) is applied to prove the number and group of differences. Statistical evaluation is carried out with software SPSS.

3. RESULTS AND DISCUSSION

Combing Force
Table 2 provides an overview of mean values of combing forces at both water hardness (0 ° dH and 15 ° dH) with the soaking time of 1 minute and 15 minutes for undamaged hair. Significant differences are highlighted with an asterisk. The fat line means that same hair was used.

Table 2: combing force for undamaged hair

Shampoo	Soaking time (min)	15 ° dH (mN)	0 ° dH (mN)	Difference (15 ° dH - 0 ° dH)
Standard shampoo	1	Mean value: 142 Standard deviation: 12	Mean value: 132 Standard deviation: 8	10*
Polymer care technology	1	Mean value: 203 Standard deviation: 9	Mean value: 167 Standard deviation: 6	36*

Standard Shampoo	15	Mean value: 147 Standard deviation: 20	Mean value: 128 Standard deviation: 4	19*
Polymer care technology	15	Mean value: 206 Standard deviation: 10	Mean value: 167 Standard deviation: 19	39*
Standard Shampoo	15	Mean value: 137 Standard deviation: 15	Mean value: 134 Standard deviation: 15	3
Silicone Technology	15	Mean value: 154 Standard deviation: 16	Mean value: 151 Standard deviation: 10	3

* significant n=10, 1 charge

Results show that soaking time has no significant influence on mean values of combing force of undamaged hair. Generally speaking, combing forces are higher in hard water than in soft water. Especially due to use of polymer care technology shampoo combing force combability of undamaged hair is worse in hard water than in soft water. Difference of mean values for standard shampoo without care range from 10 to 20 mN. For polymer care technology difference of mean values lie between 36 to 39 mN. These results show that influence of water hardness is stronger for polymer care technology compared to standard shampoo. By comparing formula of standard shampoo and polymer care technology the stronger influence on water hardness for polymer care technology is probably due to polymers PQ-7 and PQ-10. Ungewiss showed that polymers are less absorbed in hard water than in soft water. It's liable that divalent ions of hard water Ca^{2+} und Mg^{2+} are soaked by hair and therefore replace polymers (8). This could be the reason for difference of mean values for combing force for polymer care technology. Silicone technology shows unsensitivity towards water hardness. Formula of silicone technology includes polymers Jaguar C14S and Jaguar C17. This insensitivity could be due to Dimethicone and polymers for undamaged hair regardless divalent ions of hard water Ca^{2+} und Mg^{2+}. The polymers and Dimethicone can be absorbed by hair regardless presence of divalent ions of hard water Ca^{2+} und Mg^{2+}. By comparing performance of polymer care technology and silicone technology, silicone technology shows better performance regarding water hardness. Standard deviation for mean values of combing force for undamaged hair range from 6 to 20. These values can be explained by quality of hair. Hair comes from different humans and therefore quality fluctuations can not be excluded. For both shampoo technologies, mean values of combing force increase. That means hair is worse combable after product application for undamaged hair.

Results of mean values and standard deviation of combing force for damaged hair is displayed in table 3.

Table 3: combing force for damaged hair

Shampoo	Soaking time (min)	15 ° dH (mN)	0 ° dH (mN)	Difference (15 ° dH - 0 ° dH)
Standard shampoo	1	Mean value: 657 Standard deviation: 56	Mean value: 547 Standard deviation: 45	110*
Polymer care technology	1	Mean value: 488 Standard deviation: 47	Mean value: 531 Standard deviation: 28	-43*
Standard Shampoo	15	Mean value: 715 Standard deviation: 40	Mean value: 594 Standard deviation: 38	121*
Polymer care technology	15	Mean value: 565 Standard deviation: 20	Mean value: 548 Standard deviation: 55	17

Standard Shampoo	15	Mean value: 675 Standard deviation: 28	Mean value: 572 Standard deviation: 54	103*
Silicone Technology	15	Mean value: 464 Standard deviation: 23	Mean value: 350 Standard deviation: 26	114*

* significant n=10, 1 charge

Results show that soaking time (1 min and 15 min) has no significant influence on combing force for damaged hair. For standard shampoo and silicone technology shampoo mean values of combing force is higher in hard water than in soft water. The worse combability for silicone technology for damaged hair compared to undamaged hair can be explained by negative loaded surface of damaged hair. Negative load of damaged hair is stronger than for undamaged hair due to cysteic acid content. Divalent ions of hard water Ca^{2+} and Mg^{2+} can be more absorbed by damaged hair compared to undamaged hair. Therefore, polymers (Jaguar C14S and Jaguar C17) are blocked by Ca^{2+} und Mg^{2+}. Polymer care technology shows opposite behavior. This opposite behavior could be due to coacervates which unfold better in hard water than in soft water (9). For damaged hair polymer care technology and silicone technology have good performance as combing force decreases after product application. Polymer care technology shows better performance than silicone technology for damaged hair. The better performance of these shampoo technologies for damaged hair compared to undamaged hair can be explained by negative loaded surface of damaged hair. By comparing results of combing force for undamaged hair with damaged hair for standard shampoo it is noticeable that water hardness has stronger influence on damaged hair than on undamaged hair. This stronger influence can be explained by stronger negative loaded surface of damaged hair. Mahsur showed that divalent ions of hard water Ca^{2+} und Mg^{2+} are stronger absorbed by damaged hair than undamaged hair (10). Standard deviation ranges from 20 to 56. The higher standard deviation values of damaged hair compared to undamaged hair can be led back to bleaching process of hair. It can not be excluded that within one charge quality of hair differs. From literature it is known that due to increased number of functional groups damaged hair can absorb cationic polymers better than undamaged hair (11).

Sensory evaluation

Statistical evaluation shows that water hardness has a significant influence on eight attributes the sensory panel assessed. Following table provides an overview of these attributes with a significant influence from water hardness:

Table 2:

Attributes	Water hardness (°dH)	Standard Shampoo	Polymer care technology	Silicone technology
Perceived hair quantity	3 15	6,2 ↓ 7,3 ↑	-	-
Aqueous foam	3 15	-	0,4 ↑ 0,2 ↓	0,1 ↓ 0,4 ↑
Rinsing time in seconds	3 15	-	11,6 ↓ 14,7 ↑	12,7 ↑ 11,7 ↓
Ease of disentangling	3 15	-	6,0 ↓ 7,6 ↑	7,3 ↑ 6,0 ↓
Combability	3 15	-	3,2 ↓ 5,3 ↑	4,8 ↑ 3,0 ↓
Residual product	3 15	-	0,6 ↑ 0,4 ↓	-
Hair - dull, lack lustre	3 15	-	0,8 ↑ 0,5 ↓	-

Hair - soft	3 15	-	0,2 ↓ 0,6 ↑	-

Standard shampoo shows higher perceived hair quantity in hard water than in soft water and correlates with aqueous foam. The richer foam the less hair quantity. The less richness of foam in standard shampoo in hard water can be led to divalent ions of hard water Ca^{2+} und Mg^{2+}. Ca^{2+} and Mg^{2+} react with tenside system of standard shampoo. Therefore, richness of foam decreases. Regarding water hardness standard shampoo shows best performance. Regarding aqueous foam, rising time in seconds, ease of disentangling and combability polymer care technology and silicone technology show opposite behavior. Aqueous foam for polymer care technology is higher in 3 ° dH than in 15 ° dH. For silicone technology aqueous foam is higher at 15 ° dH than in 3 ° dH. This opposite behavior can be explained by different content of tenside systems in formulas. Panel rinses polymer care technology longer in hard water than in soft water. Therefore, at water hardness 15 ° dH residual product is less in hard water than in soft water. After polymer care technology application ease of disentangling and combability for damaged hair is better in soft water than in hard water. As already mentioned polymers are absorbed less in hard water than in soft water due to Ca^{2+} and Mg^{2+}. Results also show that after application of polymer care technology hair is less dull and softer in hard water than in soft water. Overall, polymer care technology shows worst performance regarding water hardness. After application of silicone technology panel rinses product longer in soft water than in hard water. Ease of disentangling and combability is for silicone technology better in soft water than in hard water. Regarding foam properties all shampoo technologies (standard shampoo, polymer care technology, silicone technology) show unsensitivity. Moreover, results show that results of physical measurement (combing force) correlate with results of sensory evaluation. Polymer care technology shows better performance of combing force for damaged hair in hard water. Silicone technology performs better regarding combing force of damaged hair in soft water.

4. SUMMARY

The following questions were addressed in this study:

Does the time for which the hair is soaked affect combing forces? (1 min. vs. 15 min.)
Measurements of combing force showed that the soaking time (1 min. vs. 15 min.) had no significant effect on combing forces for damaged or undamaged hair.

How do different shampoo technologies behave in relation to water hardness?
Different shampoo technologies (standard shampoo without care, polymer care technol- ogy and silicon technology) behave quite differently as water hardness varies.

Physical measurements of undamaged hair showed that after using standard shampoo or polymer care technology, combability was better with soft water than with hard water. Physical measurements of undamaged hair after shampooing with silicone technology were unaffected by the degree of water hardness.

Data from physical measurements of damaged hair showed that after application of standard shampoo or silicone shampoo, damaged hair was easier to comb with soft water than with hard water. However, with damaged hair polymer care technology behaved in the opposite way to standard shampoo and silicone shampoo. After applying polymer care shampoo, damaged hair was more difficult to comb with soft water than with hard water. In sensory assessments, the standard shampoo (without care) was least affected by the degree of water hardness. Polymer care technology and silicone shampoo behaved in opposite ways with respect to the attributes aqueous foam, rinsing time, ease of disentangling and combability with soft and hard water. The greatest overall effect of water hardness on the sensory evaluations was with polymer care technology.

How does the degree of hair damage in combination with water hardness affect combing forces in wet hair?
The combing force data show that the difference in combing force between 15 °dH and 0 °dH water hardness is greater for damaged hair than for undamaged hair. This leads to the conclusion that water hardness has a greater effect on damaged hair than on undamaged hair.

Are the physical data (measurements of combing force) consistent with the data from the sensory panel?
The physical data are comparable with the data from the sensory panel. With polymer care technology, damaged hair can be more easily combed with hard water than with soft water, according to the data from combing force measurements as well as from sensory assessments. However, with silicone technology, both the physical measurements and the sensory evaluations show that damaged hair can be more easily combed with soft water than with hard water.

Which attributes depend on water hardness? On which attributes does water hardness have a significant effect?
Water hardness has a significant effect on eight attributes of the shampoo panel: Perceived hair quantity, aqueous foam, rinsing time in seconds, ease of disentangling, combability, residual product, hair - dullness, lacklustre, hair - softness.

This study has shown that water hardness has a significant influence on the application of hair care products.

5. CONCLUSIONS

This study shows that water hardness has a significant influence on hair care products. Standard shampoo, polymer care technology and silicone technology behave differently regarding water hardness. Silicone technology shows best performance concerning combing force. Standard shampoo and polymer care technology are sensitive in combing force to water hardness. For physical measurement (combing force) influence of water hardness is strongest on undamaged hair applied with polymer care technology. Moreover, water hardness has significant influence on damaged hair for all shampoo technologies (standard shampoo, polymer care technology, silicone technology). On damaged hair polymer care technology shows opposite behavior compared to silicone technology and standard shampoo. By comparing combing force values of undamaged hair with damaged hair it is noticeable that influence of water hardness is stronger on damaged hair than on undamaged hair. Silicone and polymer care technology obtain effective performance on damaged hair. On damaged hair combing force increases which means combability impairs after product application. In sensory evaluation standard shampoo shows best performance. Polymer care technology and silicone technology shows opposite behavior. Influence of water hardness is strongest for polymer care technology regarding sensory evaluation. Concerning foam properties all shampoo technologies (standard shampoo, polymer care technology, silicone technology) are insensitive. In conclusion, results of physical measurements (combing force) correlate with results of sensory evaluation.

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