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Textile Cleaning

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Effect of the pre-treatment of stains with ultrasound in household laundry cleaning

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Abstract: The effect of three handheld ultrasonic devices for the pretreatment of stains on textiles was evaluated under household conditions. Twenty soiled textiles were treated and the mean increase of lightness ΔL^* of the soiled textiles was used as a measure for the cleaning effect. It was shown that the combination of a pretreatment and a washing cycle at 20 °C yields a higher mean increase of lightness, $\Delta L^* = 19.5$, compared to a 40 °C washing cycle without pretreatment, $\Delta L^* = 15.3$. The effect is most pronounced for mixtures consisting of oily soils with pigments, $\Delta L^* = 25.1$. During the pretreatment, the soil was soaked in a detergent solution and the effect of soaking was measured separately.

Keywords: pretreatment; textile washing; ultrasonic; washing performance.

1 Introduction

In textile cleaning, the parameters *chemistry*, *mechanics*, *time* and *temperature* are summarized traditionally under the name Sinner's Circle [1]. *Chemistry* is a customary term in the laundry business and is used to denote the action of the ingredients of the detergent such as surfactants, enzymes and bleach. *Mechanics* in a conventional washing process is the result of the mixing of the laundry during the process. Ultrasonic can be regarded as a special form of mechanical force. *Time* is the duration in which the other parameters are working on the stains at a specific *temperature*.

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Ultrasonic (US) is used in many cleaning applications in a liquid bath, mostly for hard surfaces, i.e. industrial component cleaning. The main effect is cavitation; in low pressure regions of the ultrasonic field steam bubbles are formed which collapse and produce fast water jets, shock waves and water currents. In liquids this takes place predominantly at interfaces with high differences of acoustic impedance between water and solid material.

Ultrasound is injected by a transducer into the liquid and passed on to the materials that have to be cleaned. As the concentration of ultrasonic energy is the highest at the transducer surface, cavitation is very likely to take place near this surface. In the US pretreatment procedures dealt with in this article, the soiled textile and the transducer surface are in close contact.

In **washing drums** for household application and washing tunnels for industrial washing, textiles are constantly mixed with a water-based washing solution in an unstructured way so that several layers of textiles are closely spaced. In particular, in horizontal axis drums this leads to a high mechanical action because laundry items are lifted in the drum and fall down on each other.

As ultrasonic is dampened by gas bubbles in liquids, its application in washing drums is unfavorable as textiles usually trap gas bubbles and produce foam during washing. Together with the fact that the textile surface shows only a small impedance change compared to water, this reduces the range, and thus efficiency, of ultrasonic.

Even in laboratory experiments outside the washing machine with no textiles in the path between transducer and textile [2, 3] only small effects could be observed; these experiments also lacked direct comparison with conventional washing efficiency. Other proposed modes of action of ultrasonic in laundry cleaning are oscillating microbubbles that lead to an enhanced local water flow which can also help to remove stains [4]. No application of ultrasonic for washing drums with a proven impact on cleaning effect is available in the market.

In the work of Gallego-Juarez et al. [5], a set-up for cleaning flat textiles such as in textile processing was proposed. Fabric in a flat format was moved parallel to a flat ultrasonic emitter in a shallow bath. Cleaning

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performance was measured for three different types of soils and compared to a short washing cycle in a washing machine. It was stated that for one stain cotton soiled with carbon black and olive oil (EMPA-101), ultrasonic had a better cleaning performance than an unusually short washing cycle at 25 °C. As no specific data of the washing process were given, it was not clear if the difference is of practical relevance and if this is true for other types of stains.

2 Experimental

The aim of the experiments was to see whether under favorable conditions the ultrasonic (US) devices showed a cleaning effect of practical relevance in household conditions. As a preliminary experiment, the influence of detergent concentration was determined. This was followed by the main experiments, which evaluated the effect of the US devices.

2.1 Measurement of cleaning effect

In order to measure washing performance, a set of 20 different stains from the Center for Testmaterials B.V. (CFT) was used, Table 1. Six stains were mainly sensitive to bleach, eight to enzymes and six to mechanical action; the textile substrate was cotton.

Some of the stains were mixed with additional pigments like soot in order to make it easier to measure stain removal. The cleaning effect was assessed by the CIELAB lightness L^* according to DIN EN ISO 11664-4 [6]. L^* was measured with the reflection spectrophotometer CM-2600d from Konica Minolta Inc. The value $L^* = 0$ corresponded to black and 100 to white. Higher values indicate a better cleaning effect with the colored stains being removed from the white textile substrate.

Table 1: Stain set used for testing the cleaning performance. The stains on cotton are divided into three groups, which are predominantly sensitive to particular properties of the detergent or washing system.

Type	Description	Sensitive to
CFT CS-12	Black currant	Bleach
CFT CS-15	Blueberry juice	
CFT CS-49	Coffee	
CFT CS-08	Grass	
CFT CS-103	Red wine, not aged	
CFT CS-97	Tea	
CFT CS-61	Beef lard	Enzyme
CFT CS-01	Blood, aged	
CFT CS-10	Butterfat with colorant	
CFT CS-44	Chocolate drink	
CFT CS-68	Chocolate ice cream	
CFT CS-26	Corn starch, colored	
CFT CS-37	Full egg with pigment	
CFT CS-06	Salad dressing/natural black	
CFT CS-216	Lipstick, red	Mechanics
CFT CS-17	Make up	
CFT CS-05S	Mayonnaise/carbon black	
CFT C-02	Olive oil/soot	
CFT CS-32	Sebum/soot	
CFT C-01	Soot/mineral oil	

2.2 Experimental conditions in main experiments

The combination of experimental conditions in the main experiments is shown in Figure 1.

The performance was assessed as difference of L^*-values of each stain before pretreatment and after the washing process. If the colored stains were cleaned, L^* increased. Pretreatment with the US devices was done at room temperature and was followed by a washing cycle at 20 °C or 40 °C. Energy consumption of the handheld ultrasonic devices was between 3 and 9 W. The pretreatment was done in a shallow tub filled with 400 mL of a detergent solution with a concentration of 6 g/L at room temperature. As detergent, the liquid Persil Universal gel from Henkel AG & Co. KGaA was used. It contained surfactants, builders, enzymes and more minor components, but no bleach. The stains were also immersed completely in the liquid during the pretreatment with US.

For the washing cycles the program *cotton* with the option *short* in a Miele Softtronic 1935 WTL was used at 20 °C or at 40 °C. In order to control the experimental conditions program time, water inlet and temperature were recorded, as found in Table 2.

Under household conditions, the load usually contains high amounts of soil types such as body soil and dust which have an influence on detergency, but are barely visible. In order to imitate this, soil mixtures are added in laboratory experiments to the clean load. This is also recommended for detergent testing [7]. Sheets of SBL 2004 from wfk Testgewebe GmbH were used as soil ballast for this purpose. One piece contained 8 g of soil. As clean ballast load 5 kg textiles were used which consisted of 70% cotton and 30% polyester.

During US pretreatment each of the 20 stains was treated manually by moving the device evenly over the surface of the whole spot of (5×5) cm^2 for 30 s. The overall time for pretreatment and handling for all stains before washing was 15 min. The pretreatment sequence of the stains was reversed in consecutive experiments. As the pretreatment was done in a detergent solution, it was difficult to distinguish between the effect of soaking and that of US application. Therefore, experiments without US application were done; in this case the stains were soaked at room temperature in the detergent solution for 15 min without further treatment and washed at 20 °C or 40 °C. In order to compare the results to the conventional washing process, experiments with stains without pretreatment or soaking were also conducted at 20 °C and 40 °C.

2.3 Handheld US-pretreatment devices

Three handheld devices were used. During the pretreatment procedure in a liquid detergent-containing solution, the transducers had direct contact to the textile. The shape of the contact surface is shown in Figure 2.

The devices from Sharp and Vitun had rectangular flat transducers and were powered by a rechargeable battery. The Electrolux device had a hemispherical form and was connected to the mains. After some time of use, cavitation corrosion could be observed at the transducer tips of Vitun and Sharp. For this reason, results were controlled against new devices which showed no obvious differences.

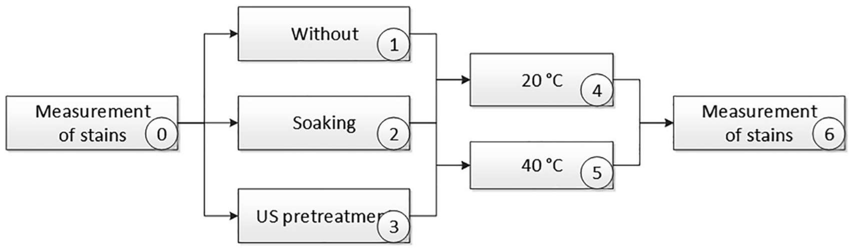

Figure 1: Sequence of experiments and process variables. Either there was no pretreatment (1), only soaking in detergent solution (2) or pretreatment with an ultrasonic device (3). Afterwards, the stains were washed either at 20 °C (4) or 40 °C (5).

3 Results and discussion

3.1 Influence of detergent concentration

In preliminary experiments, the concentration of detergent was varied. Tests were carried out twice for each concentration. Pretreatment was done in a similar manner to the main experiments; the washing cycle was done at 20 °C. As cleaning effect, the mean ΔL^* of all 20 stains between the application of US and the experiment with only soaking was calculated, shown in Figure 3.

The experiments without detergent using only deionized water or with concentrated detergent showed only a low washing performance, surprisingly on the same level. The cleaning effect of two concentrations of diluted detergent of 6 and 9 g/L in deionized water showed no difference statistically, but on a higher level. The low performance of the deionized water was to be expected as no surfactants were available to remove and solubilise the stains. Another reason could be that the surface tension of water is higher compared to detergent solutions and this can lead to a reduced cavitation. The undiluted detergent had a high viscosity which reduces cavitation as well and leads to a slower interaction of surfactants with the stains. A diluted detergent solution of 6 g/L was used in the pretreatment procedures in the main experiments.

3.2 Properties of ultrasonic devices

The ultrasonic devices are characterized by the working frequency, as seen in Figure 4. The frequency was measured in a stainless-steel water bath (30 × 24 × 14.5) cm^3 at a scanning rate of 1 MHz with the device cavispector from Köchel Verifications GmbH. The sensor was placed in a distance of 2 cm from the transducer, which itself was immersed about 2 cm from the surface in the middle of the bath.

The frequency range for the ultrasonic devices is shown in Figure 4; the working frequency matched the manufacturer's specifications: Electrolux: 46 kHz, Sharp: 38 kHz, Vitun: 51 kHz. The base-line of Electrolux was lower compared to the other devices. One reason may be the hemispherical transducer geometry, which could lead to a more even distribution of the ultrasonic radiation.

The gross power consumption of the handheld device from Sharp was estimated by the battery capacity 900 mAh and running time 30 min as 7–9 W, this leads to 29 W/cm^2 at the transducer tip. The power of the flat transducer used in Gallego-Juarez et al. [5] was reported to be (0.6–1.2) W/cm^2 at 20 kHz. Therefore, a washing effect could be expected,

Table 2: Recorded experimental conditions: time, water, energy, and temperature.

Washing program	Time/min	Water/L	Energy/kWh	Temperature/°C
Cotton, short 20 °C	107	*70 ± 2*	*0.24 ± 0.02*	*20.5 ± 0.5*
Cotton, short 40 °C	107	*70 ± 1*	*0.76 ± 0.01*	*39.0 ± 0.1*

The values include the standard deviation.

Figure 2: Transducer shape of the handheld US pretreatment devices from Electrolux, Sharp and Vitun.

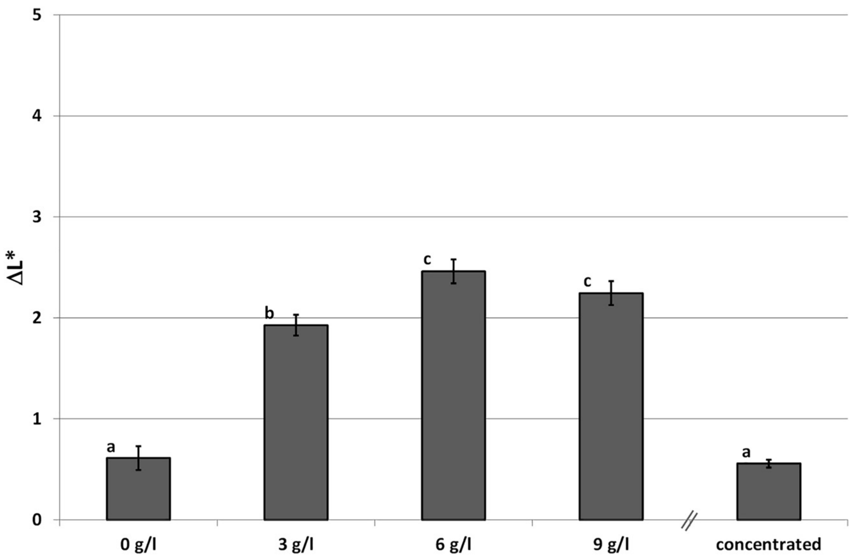

Figure 3: Effect of detergent concentration on lightness after US pretreatment and a following washing cycle at 20 °C compared to no pretreatment and washing. 0 g/L corresponds to deionized water, “concentrated” corresponds to undiluted detergent. Error bars are min- and max-values. Letters a, b and c: Significance levels according to Tukey at 95% level.

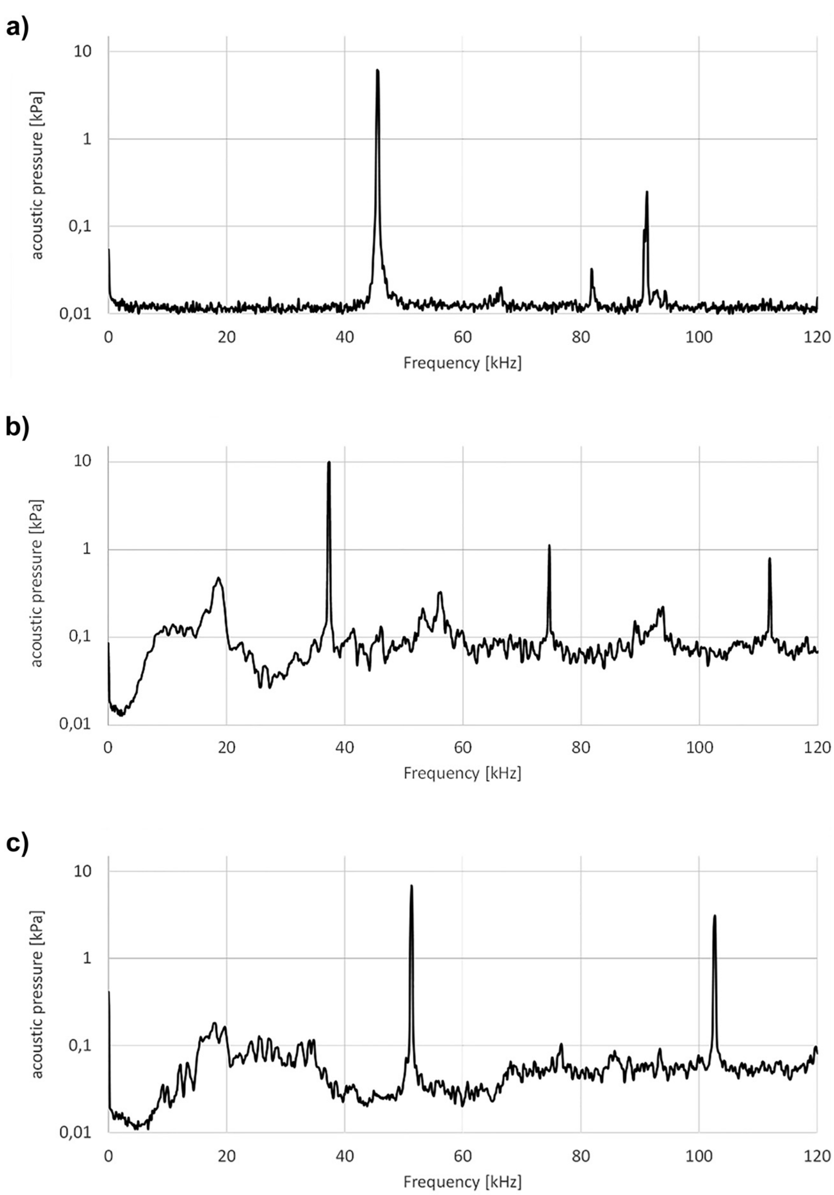

Figure 4: Frequency range of different ultrasonic devices for the devices from (a) Electrolux, (b) Sharp and (c) Vitun.

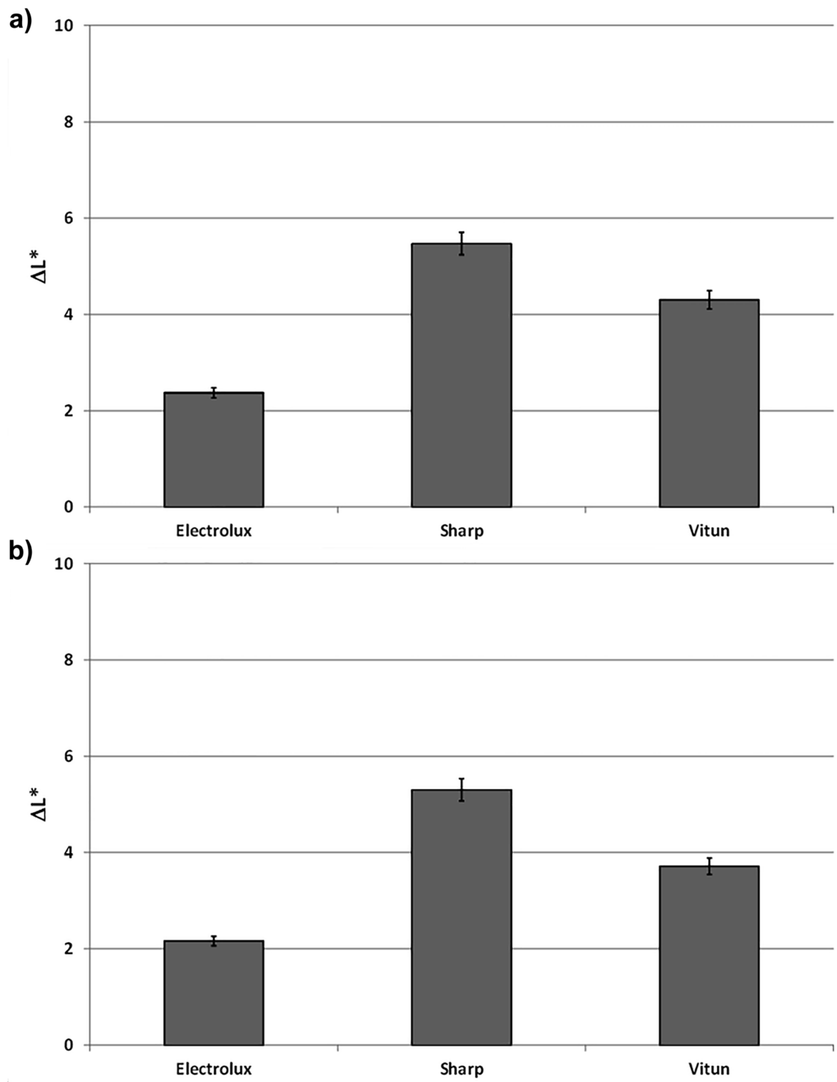

Figure 5: Mean difference of L^* values of the combination of US pretreatment with a following washing cycle compared to soaking and washing: (a) following washing cycle 20 °C, (b) following washing cycle 40 °C. Error bars show standard deviation.

even if the efficiency of the ultrasonic generators in the handheld devices was low.

3.3 Cleaning results

To decide whether the the US pretreatment showed a significant effect, the cleaning performance was compared to soaking without US and tests without pretreatment. Only if the US treatment was significantly better in both cases with one device, the US treatment with that specific device was regarded as being overall better for this kind of stain.

Most stains show an overall better cleaning with US pretreatment regardless of whether the following washing cycle was at 20 or at 40 °C. Only the stains butter fat, black currant and beef lard partly showed no significant effects. All stains were overall better removed with US compared to soaking without US when followed by washing cycle at 20 °C only for the Sharp device.

For a first overview, Figure 5 shows the mean improvement of all 20 stains after pretreatment and a following washing cycle at 20 °C and 40 °C. In the following graphs, only the difference ΔL^* between the pretreatment US and soaking are discussed as an effect. Higher ΔL^* values show a better cleaning performance as can be seen in Figure 5.

The performance of the devices from Sharp and Vitun is at a higher level compared to that of the Electrolux device, which showed the lowest performance in all tests. This may be because the transducer of Electrolux has a smaller contact surface; this can lead to an uneven effect during the manual pretreatment.

The results for Sharp device are divided into stain groups to see which stains are weaker or more affected by US. As an example, the results at 20 °C are shown in Figure 6.

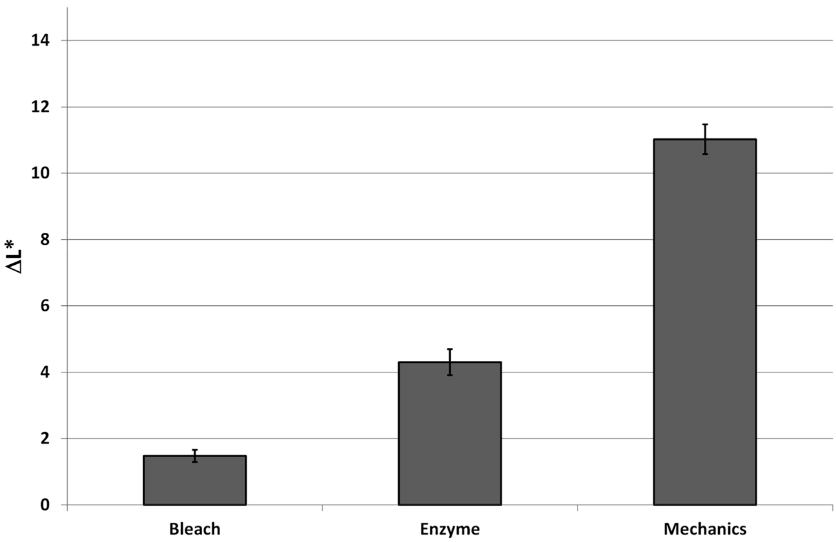

Figure 6: Mean difference between US pretreatment with the Sharp device versus soaking for different stain groups sensitive to bleach, enzymes or mechanical action. After pretreatment and after soaking, the stains were washed at 20 °C. Error bars show standard deviation.

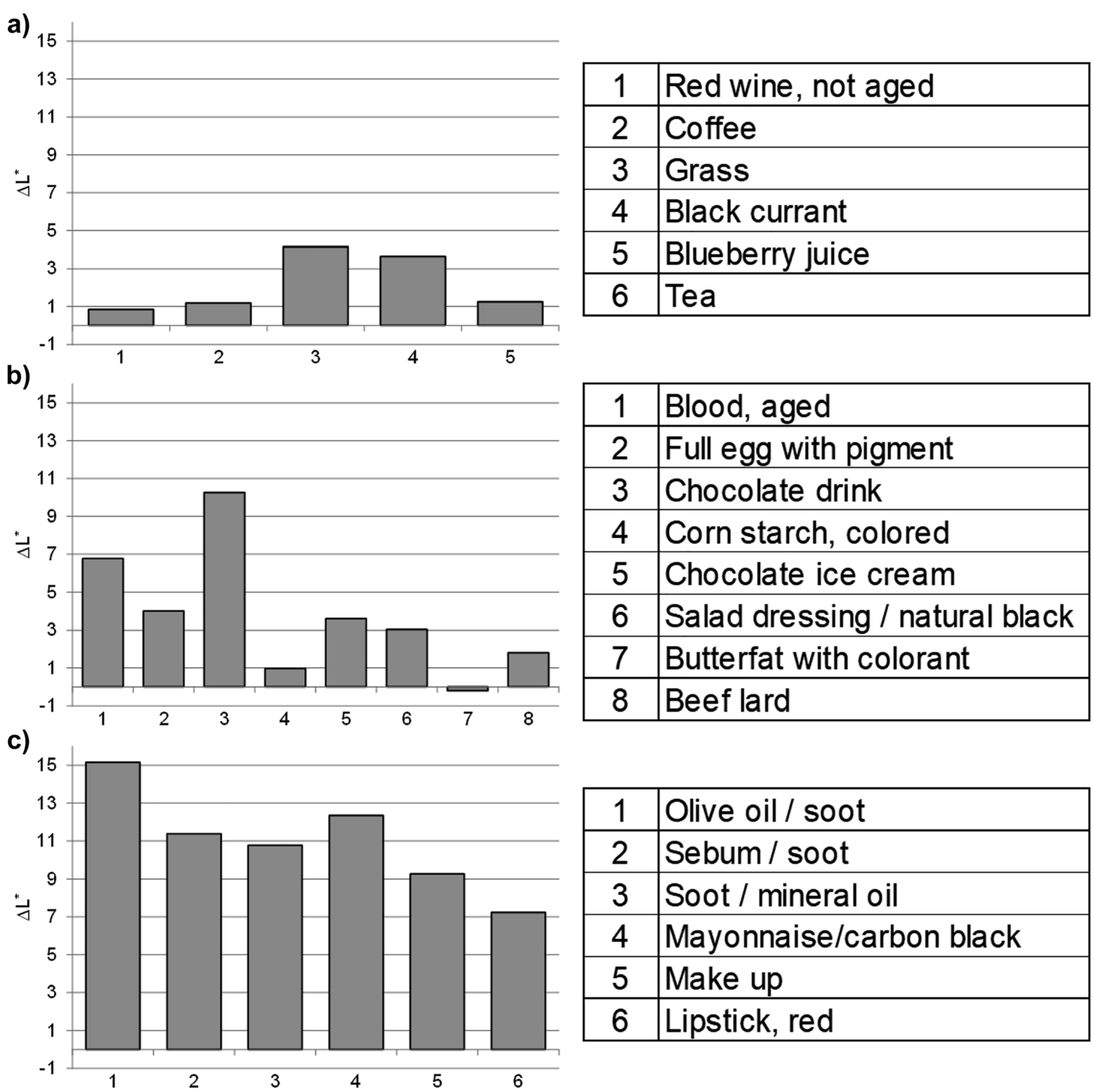

Figure 7: Effect of US pretreatment versus soaking on individual stains from different stain groups, stains were sensitive to (a) bleach, (b) enzymes, (c) mechanic.

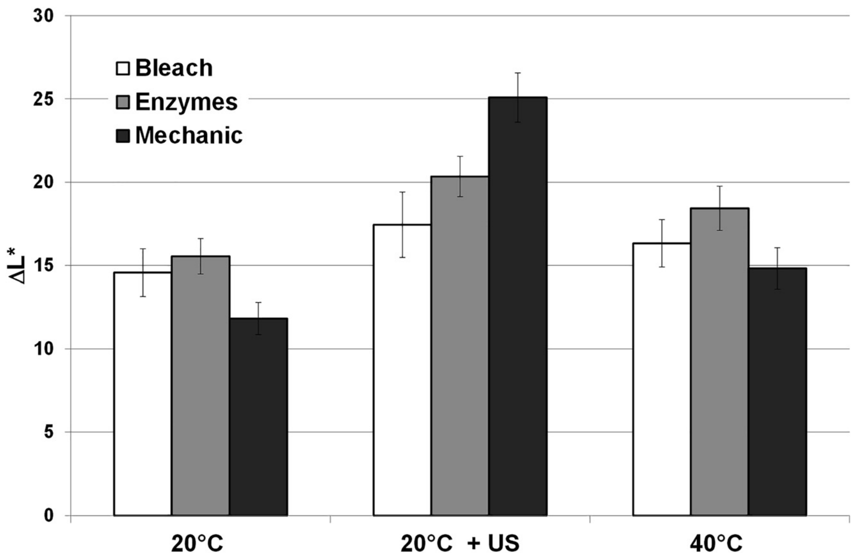

Figure 8: Comparison of the cleaning effect of 20 °C and 40 °C washing cycles without pretreatment (20 °C, 40 °C) and the combination of an ultrasonic pretreatment and a 20 °C washing cycle (20 °C + US). ΔL^* refers to the stain before any treatment. Mean values for the stain groups that are sensitive to bleach, enzymes or mechanical action. Error bars show standard deviation.

Stains sensitive to mechanics showed the highest cleaning effect of US. The detergent contained no bleach but enzymes. As enzymes should also be active in the soaking pretreatment, only minor effects on stains, which were optimized to show the effect of bleach or enzymes, were expected. Nevertheless, stains from the bleach and enzymes sensitive group also showed a significantly enhanced lightness in the runs with US pretreatment compared to soaking.

The performance on different stains from each group is shown in Figure 7. In the group of stains which react to mechanics, stains containing pigments like soot are better removed compared to stains with lipstick without additionally added pigments. This is in accordance to Junhee et al. [2] who calculated that carbon black in stains can be removed by ultrasonic cavitation as well as by oscillating bubbles. As most stains showed an overall effect of ultrasonic pretreatment, the scope of application of ultrasonic pretreatment seems to be very broad.

Comparison of a US pretreatment followed by a washing cycle at 20 °C and a washing cycle at 40 °C without pretreatment shows that the effect of the US is of practical relevance, Figure 8. In this case ΔL^* is the difference after the treatment and compared to the stain before any treatment.

The mean effect of all three stain groups was $\Delta L^* = 19.5$ for a US pretreatment with washing at 20 °C, but only $\Delta L^* = 15.3$ if the stains were not pretreated at all and washed at 40 °C.

4 Conclusions

It was shown that a 30 s pretreatment with a US device in a detergent-containing solution followed by a washing cycle at 20 °C has a better cleaning effect compared to a 40 °C washing process without pretreatment.

Stains containing particulate pigments like soot are removed more efficiently by ultrasonic pretreatment. Whether only the pigments in the stain mixtures were removed selectively or whether the mixtures were evenly removed could not be decided, as only the lightness was measured which reacts strongly to pigments like soot. However, as also nearly all stains without pigments showed an overall cleaning effect, it is likely that US pretreatment removes a broad variety of stain materials.

As cavitation can even corrode metallic surfaces, fiber damage is also a relevant topic. In the experiments, no changes of the textiles could be observed visually after one run. Additionally, the friction between transducer and the textile will have an impact on fiber damage. However, in the case of randomly distributed stains in textiles, there is little chance that one and the same textile area will be treated several times with an US device. For heavily soiled cloth, pretreatment will be too time-consuming and therefore a washing program should be chosen without pretreatment. But for working clothes with typical stain patterns or for a broad application of this technology, the impact of fiber damage should be estimated.

During the experiments, a temperature increase of the US transducer was observed which could also lead to an enhanced cleaning performance. In order to evaluate the isolated effect of US, the influence of temperature and friction on the cleaning effect should be addressed specifically in future experiments.

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