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Multisensory Interactions between Olfaction and Touch: The Influence of the Trigeminal and Olfactory Sensation of an Odourant on Roughness Perception.

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Abstract

In this study we investigated the influence of the olfactory and trigeminal sensation of an odourant on roughness perception. We expected that people would judge the tactile surface roughness of four sandpapers as higher when they were exposed to a substance with a trigeminal component (alcohol), and lower when they were exposed to Phenylethylalcohol (PEA, rose odour), compared to a no-odour (clean air) condition. Our results indicated that the participants could discriminate all four sandpapers on basis of their perceived roughness. However, there was no significant main effect of chemosensory and no significant interaction between chemosensory and sandpaper roughness. Despite the lack of significance, the results revealed that the mean rating responses on roughness were higher in the alcohol condition, and lower in the PEA-condition, compared to the no-odour condition. We also found a significant effect of gender for the roughness ratings in the PEA condition. Alternative explanations for the found results and suggestions for further research are discussed.

Keywords: multisensory interactions, olfaction, trigeminal, tactile perceptions, roughness, touch

Multisensory Interactions between Olfaction and Touch: The Influence of the Trigeminal and Olfactory Sensation of an Odourant on Roughness Perception.

Multisensory interactions between tactile perceptions and the other senses

In recent years there is a growing interest in multisensory interactions between tactile texture perception and the other senses. According to Lederman *'perceiving the texture of a surface by touch is a multisensory task in which information from several different sensory channels is available. In addition to cutaneous and thermal input, kinesthetic, auditory, and visual cues may be used when texture is perceived by touching a surface'* (Lederman, 1982, p. 131). Lederman's statement is confirmed by research showing that texture perception is influenced by audition (e.g., Jousmäki & Hari, 1998; Werner & Schiller, 1932; Lederman, 1979; Guest et al., 2002; Lederman & Klatzky, 2004) and vision (e.g., Werner & Schiller, 1932; Guest & Spence, 2003a,b). Guest, Catmur, Lloyd & Spence (2002) for example showed that people's perception of roughness of sandpapers is influenced by hearing different sounds while touching them. Jousmäki and Hari (1998) showed with the so called 'parchment skin illusion' that the perceived roughness/moisture of the palmar skin decreases and the smoothness/dryness increases when participants hear the sounds produced by their own hand movements. This parchment skin illusion may reflect a multisensory integration phenomenon, which supports people in distinguishing roughness of different textures. The inter-modal interaction between vision and touch is for example shown by Guest and Spence (2003a). Discrepant haptic information affected visual discriminations of roughness in their experiment, but discrepant visual information did not affect haptic discriminations of roughness. This result showed that haptic input cannot be filtered when someone assesses roughness using visual cues, whereas visual input can be ignored when someone assesses roughness using haptic cues. That touch is ecological more suited to assess roughness than vision may account for this effect.

That taste evaluations are influenced by haptic input is shown in a study of Krishna and Morrin (2008), in which consumers evaluated the quality of the same water as worse when they were drinking out of a flimsy, disposable cup through a straw while holding it (low-quality haptic input), than when they were not holding it. An interesting finding of this study is that only people who have a low need for touch (haptically non-expert consumers, or consumers for whom touching products is not particularly motivating) are influenced by these haptic cues, which actually give no information about the quality of the product.

Multisensory interactions between olfactory perceptions and the other senses

Olfaction can interact with visual (e.g., Bornstein, 1936; Allen & Schwartz, 1940; Gilbert et al., 1996; Morrot et al., 2001) and gustary (Rolls, 2004; Stevenson & Boakes, 2004) perception as well. Morrot et al. (2001) for instance showed that the olfactory judgments of even experienced wine tasters are biased by visual cues, such as colouring a glass of white wine red. Demattè, Sanabria and Spence (2006) showed that participants selected colour hues for odours with a significant agreement within and between participants. Reliable colour-based odour associations, as for instance brightness and saturation, are observed in participants as well (e.g., Kemp & Gilbert, 1997; Schifferstein & Tanudjaja, 2004).

Multisensory interactions between tactile and olfactory perceptions

Despite the many studies about multisensory interactions of tactile and olfactory perceptions with vision and audition, there is still not much known about the interaction between olfaction and touch. Laird (1932) was the first who investigated the influence of odour on tactile perception. He asked 250 housewives to feel four identical silk stockings that were impregnated with different scents (narcissus or natural) and judge their quality. The housewives preferred the pair of stockings that was impregnated with a narcissus scent over those with a natural scent on their textural quality, while none of the housewives reported the scent of the stockings as the reason for their preference. Power (1956) showed that simply changing shampoo fragrance enhanced product evaluations. People reported that a shampoo with another fragrance lathered and rinsed better, while none of the participants mentioned noticing the fragrance of the shampoo (in accordance with Laird's study). Demattè, Sanabria, Sugarman and Spence (2006) followed up Laird's study and showed that the presence of a pleasant lemon odour versus an unpleasant animal odour influences the perceived softness of fabric swatches. The simultaneous presence of a lemon odour had the effect that participants rated four fabric swatches that were different in roughness as more soft than when they smelled an animal odour. This effect could be due to an associations between a pleasant/unpleasant odour (most of the participants rated the lemon odour as being pleasant and the animal odour as being unpleasant) and a pleasant/unpleasant feeling (soft versus rough). This is called an assumption of correspondence (Bone & Jantrania, 1992; Schifferstein & Michaut, 1999), which is driven by experiences in everyday life, for example the associations with soft and clean that are created when we smell the odour of cleaning products (lemon or flowers).

A recent study by Croy, Angelo and Olausson (2014) showed that an unpleasant odour can influence the touch pleasantness of slow and fast brush stroking delivered by a robot to the forearm. When participants were under the influence of an unpleasant odour (civette, smelling like faeces) they rated both types of brush strokes less pleasant than in the odourless condition. This effect was moderated by disgust sensitivity.

The influence of olfaction on roughness perception

In the present study we will further investigate the interaction between olfaction and touch. We will investigate the influence of odour on the perception of texture, and in particular on roughness in accordance with the study of Demattè et al. (2006) and Guest et al. (2002). The influence of olfaction on roughness perception may be important for cleaning products, as the producers of cleaning products may want to create a clean perception of a surface after use of their cleaning product, by making the users perceive the product scrubs everything away (from rough) until the surface is very smooth (to soft, which is associated with clean), or may want to promote consumers spending effort on cleaning by perceiving the surface to be cleaned as rough. If odours can make people perceive something more rough/smooth, the addition of a particular odour to cleaning products may enhance or reduce this perception and lead to greater user satisfaction.

Olfactory and trigeminal sensations of an odourant and perceived tactile roughness

We expect that odours have an influence on perceived roughness. Because almost all odours evoke not only olfactory, but also trigeminal sensations we are interested in the influence of both these sensations on perceived roughness. The trigeminal nerve is one of the largest cranial nerves and is divided in the ophthalmic nerve, the maxillary nerve, and the mandibular nerve. These nerves innervate the ocular, nasal, and oral branches. The former nerve contains only sensory fibers, whereas the other nerves exist of sensory and motor fibers. The trigeminal ganglion contains the cell bodies of all three divisions (Doty et al., 2004). The trigeminal nerve is activated by chemosensory substances, which can result in haptic sensations, such as the prickling, fresh, or burning feeling that odours can evoke (e.g., chilli pepper and menthol). As these sensations get more intense, they can be perceived as irritating or painful. Also temperature, touch and pressure are perceived by the trigeminal system (Lundström & Boesveldt, 2010).

Every cleaning product contains substances such as solvents which tend to have trigeminal properties (such as alcohol). Imagine for example the prickling feeling of alcohol in your nose while cleaning the window shield of your car with window cleaner. This makes the investigation of this sensation of odour extra interesting for our possible implication.

Because the trigeminal nerve evokes haptic sensations as a prickling feeling, the trigeminal system thus can be seen as a kind of tactile sense. Chemosensory substances in odours activate the trigeminal sense, which results in tactile sensations. It may be concluded that there is a relation between olfaction and touch. Furthermore, it seems that various studies indicate that the multisensory interactions between a sensory modality and tactile perception are based on a similar association. The study of Guest et al. (2002) for example indicated that hearing a high frequency sound increases the perceived roughness of abrasive papers. In addition, research of Zampini and Spence (2004) showed that auditory frequency influences tactile perceptions. This effect was seen in participants who had to judge the crispiness of potato chips while they heard the creaking sound as they were biting on it. These studies thus showed that tactile perceptions can be enhanced by experiencing sensations of other modalities which give raise to similar associations. In our study, a trigeminal stimulus can give a prickling feeling in the nose and roughness can give a prickling feeling to the fingers. Because of the extra tactile prickling the trigeminal stimulus evokes in the nose, a prickling rough feeling may be enhanced. Surfaces therefore may feel more rough when simultaneously an odour with trigeminal properties is presented. Because this relation between chemosensory substances in odours and haptic sensations, we expect that odourants with trigeminal properties may enhance perceived tactile roughness.

Based on the above we expect that (H1) people will judge the tactile surface roughness of objects as higher when they are exposed to a substance with a trigeminal component, compared to a no-odour (clean air) condition while touching the objects.

If a trigeminal substance does have the effect that it makes people perceive surfaces rougher, producers of cleaning products can take this into account. This effect may be positive for the efficiency of a cleaning product, if the goal of the producers is to change cleaning behavior. When users perceive a surface rougher while they are cleaning it, they will probably scrub harder to make the surface softer. This will make the surface cleaner, which will lead to greater user satisfaction. Prior research has indicated that cleaning behavior in a similar way can be influenced by scents. A study of Holland, Hendriks and Aarts (2005) showed that the presence of a scent that is typically associated with cleaning products can enhance cleaning behavior. People who ate a crumbling biscuit in a room after they were exposed to a lemon (cleaning) scent, significantly showed more cleaning behavior (keeping the table clean by making hand movements at the table) than when they were not exposed to that odour. This provides evidence that odour unconsciously can influence cleaning behavior and therefore may also enhance rubbing behavior during cleaning.

Besides the influence of trigeminal sensations on roughness perception we are interested in the influence of the olfactory sensations of an odour on perceived roughness as well. To investigate this influence we will use Phenylethylalcohol (PEA), a rose flavoured odour used in prior research (e.g., Bensafi et al., 2013; Croy et al., 2014; Seo et al., 2010) which has minimal intranasal trigeminal properties (Cometto-Muniz & Cain, 1990; Brand & Jacquot, 2001). In these prior studies PEA is classified as a pleasant odor. As described earlier, the results of the study of Demattè et al. (2006) could be due to an association between a pleasant lemon odour and a pleasant soft feeling and an unpleasant animal odour and an unpleasant rough feeling. Because PEA is classified in most studies as a pleasant odour, there may be a similar association between a pleasant rose odour and a pleasant soft feeling.

There may be other associations between rose-odour and haptic perceptions as well. Research of Spangenberg, Grohmann and Sprott (2005) showed that semantic associations exist between two different senses (such as Christmas music and a Christmas scent). In line with this finding, a study of Krishna, Elder and Caldara (2010) showed that there are similar associations between smell and touch, such as the association of rough haptics with masculine and soft haptics with feminine. Because flower odours are generally associated with femininity (Jellinek, 1994) and rose odour reflects softness, femininity and sensitiveness (Thiboud, 1994), we expect that there may be an assumption of correspondence between PEA and a soft feeling. There may also be an assumption of correspondence between rose-odour and a soft feeling, which can be driven by the association with soft rose leaves when we smell a rose odour, or by the association with soft and clean that could be created when we smell the (floral) odour of cleaning products. Surfaces may feel less rough when simultaneously a rose-odour is presented, because of these associations with femininity and soft that are created when we smell a rose-odour.

Based on the above we expect that (H2) people will judge the tactile surface roughness of objects as lower when they are exposed to PEA, compared to a no-odour (clean air) condition while touching the objects.

Due to the ‘chemical’ or artificial rose odour nature of PEA, we expect that there is a chance that not everybody will like PEA. We will therefore look at the effect of PEA on roughness perception apart for likers and dislikers as well. If olfaction does have an effect on roughness perception, we expect that the mean ratings on roughness will be different under the influence or absence of an olfactory/trigeminal stimulus.

Method

Participants

Twenty-four non-smoking participants (12 males and 12 females) in a range of 18-50 years (mean age of 35 years) and selected from the TNO participant database took part in the experiment. They reported having a normal sense of smell and no history of olfactory dysfunction. We selected non-smokers, because research showed that smokers are poorer at detecting Phenylethyl alcohol compared to non-smokers (Hayes & Jinks, 2012). All participants were naïve to the purpose of the experiment: we told them that we were investigating roughness perception without vision and hearing. Participants were requested not to use hand lotion and perfume in the morning of the experiment, to make sure this would not influence the roughness ratings (Verrillo, Bolanowski, Checkosky, & McGlone, 1998;

Gerhardt, Strässle, Lenz, Spencer, & Derler, 2008). The participants received 25 Euros for participating in the experiment which took +/- 1.5 hours. The participants read and signed an informed consent prior to the experiment. The experiment was conducted in conformity with the ethical standards of the 'World Medical Association Declaration of Helsinki'. The IRB (Institutional Review Board) approved the study.

Apparatus and materials

Six sandpapers (3M ™, WetorDry ™) of different roughness were used as the tactile stimuli. These sandpapers were mounted in six plastic photo frames of 10x15 cm (grit values: 60, 80, 180, 280, 400 and 500, Heller, 1982). The grit value is the amount of sharp particles per inch^{-2} and was adopted as a measure/criterion for the tactile roughness. The smaller the grit value, the rougher the sandpaper feels (Heller, 1982). Thus a lower grit value means a rougher sandpaper. A pilot study indicated that the different sandpapers were discriminable on their perceived roughness. The physical roughness of the six sandpapers was determined by microscopic examination. See Appendix A for the plots and images of the roughness of the six sandpapers. The participants were blind-folded by taped pilot glasses and asked to put on sound-attenuating earmuffs (BILSOM 717 (700-Series), EN 352-1) which reduced the noise by 23 dB. These earmuffs reduced the noise to an extent that the participants were still able to communicate with the experimenter. By wearing the taped pilot glasses and earmuffs the participants could feel the sandpapers without seeing them and hearing the sound that their finger rubbing made on the surface, to eliminate visual and auditory contributions to the texture perception. The participants' hands were gloved by cotton work gloves, with the index finger of the glove of their preferred hand removed. In this way all participants were restricted to touching the sandpapers with the top of the index finger of their preferred hand.

One concentration ethanol was used (73.5% volume percentage, diluted with Propyleneglycol (PG)) as the trigeminal stimulus and one concentration Phenylethyl alcohol

(PEA, 25% volume percentage, diluted with PG) as the olfactory stimulus. Ethanol appears to be an effective olfactory and trigeminal stimulus and can evoke nasal irritancy (Cometto-Muniz & Cain, 1990; Mattes & DiMeglio, 2001). There was a no-odour (control) condition as well, in which only clean air was presented. The measurements were performed in three rooms which were equal in size (3.5 x 5.5 x 2.8 m), temperature (20 °C), and were shielded from external noise. PEA, alcohol or no-odour was presented in each of the three rooms.

In each room the participants had to judge the roughness of the sandpapers on a scale that ranged from 0 to 9 (0 = “ least rough’’ and 9 = “ most rough’’). In each room the participants first felt the roughest sandpaper (grit value 60) and the softest sandpaper (grit value 500), to have a reference for the task. There were no ratings given on these two sandpapers. The participants felt the sandpapers in a randomized order, and the samples were renewed after every four participants in order to avoid any impairment of the sandpapers through extended touching by participants.

The ambient odour was continuously presented in the room while the participants made their responses regarding the roughness of the sandpapers. For the delivery of the ambient odours scent diffusers were used in the PEA-condition and the alcohol condition (XENON electric scent diffuser). Initial pilots on trial and error basis were conducted to define the amount of odour that had to be delivered by the diffusers, in such a manner that the odour was above the detection threshold, but just beneath the awareness threshold. The awareness threshold refers to a level of odour at an intensity that someone will not notice it, unless attention is paid to it. On basis of the pilots we have chosen for a setting in which the diffusers blew with a time interval of 25 seconds, for a period of 30 seconds the odour into the room. The diffuser was located under the table where the participant took place. A tube led the air with the particular odour from the diffuser in the direction of the participant. We did not use a scent diffuser for the control condition, because there was no third scent diffuser accessible.

Because the earmuffs did not totally eliminate the sound that the diffusers made, we recorded this sound on a laptop and played it from under the table in the no-air condition. In this manner we were sure that the circumstances were equal in all three rooms and that the presence or absence of background noise of the scent diffuser could not influence the roughness ratings. See Appendix B for pictures about the set-up of the study.

The instructions and the response scale on which the participants made their rating responses were verbally explained by the experimenter before the experiment started. During the tasks the participants answered verbally, while the experimenter collected the responses on a response sheet.

Design

To test the hypotheses we used a within-participants repeated-measures design, with as independent variables chemosensory (PEA, alcohol and no odour) and sandpaper roughness (grit value 80, 180, 280 and 400). The experiment consisted of three blocks of 48 trials (four trials of four sandpapers per each chemosensory condition). The presentation of the four sandpapers in the three chemosensory conditions was randomized, just as the presentation of the chemosensory conditions.

Procedure

The participants were welcomed in the waiting room. They took place at a table with magazines and a bottle of water. The three experiment rooms were located around the waiting room. The participants first verbally received instructions from the experimenter, after which they read and signed an informed consent. Then the participants were blind-folded and asked to put on earmuffs and guided to one of the three rooms by the experimenter, where the experimenter positioned them at a table.

In each room the participants rated the roughness of the four sandpapers in a randomized order, as described above. Each sandpaper was presented by the experimenter directly in front of the participant. Each sandpaper was presented four times in four trials per chemosensory condition. Every 30 seconds the next sandpaper was presented, to make sure that the time participants were spending in the room was the same for each participant. In this way this could not influence the roughness ratings. The task in each room took 10 minutes.

After the 16 trials in each room, the participants had a 5-minutes break in the waiting room, were they removed their glasses and earmuffs and read a magazine. They could drink water if they wanted. The 5-minute break after the task in each room functioned to minimize carry-over effects from the chemosensory and to avoid reduced sensitivity through extended touching of the sandpapers. After the break the participant was guided to another room to perform the same task again. In this way the participants were doing exactly the same task (in the same order) in each chemosensory condition. After the third and last room, the participants were guided back to the waiting room. Here they had to fill out a form about demographics and were asked whether they noticed something in the environment during the three tasks. Then the participants were directed for the last time into the rooms with eyes and ears open, where they had to rate the intensity and pleasantness of the odour in the room on a scale that ranged from 0 to 9 (0 = “ not detectable and 9 = “ very intense’’; 0 = “ very unpleasant and 9 = “ very pleasant’’). See Figure 1 for a schematic representation of the experiment.

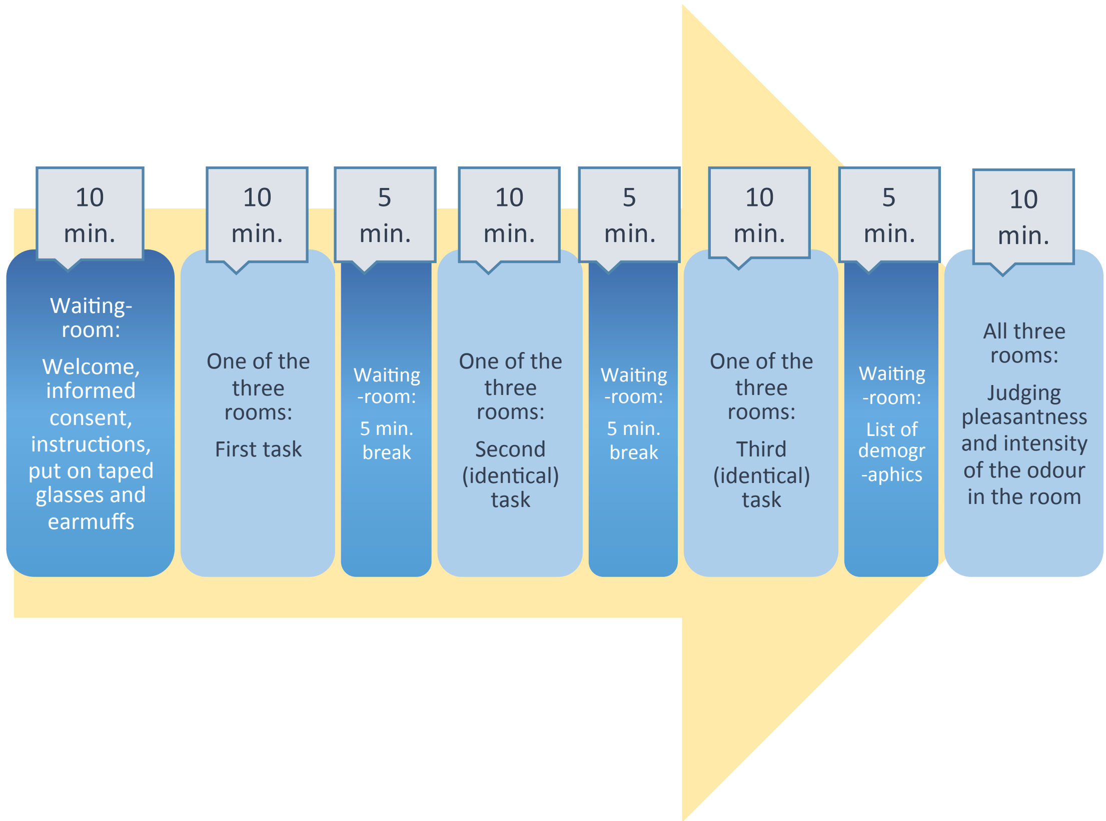

Figure 1. Schematic representation of the experiment.

Results

A within subjects repeated measures ANOVA with chemosensory (PEA, alcohol and no-odour) and sandpaper roughness (grit value 80, 180, 280 and 400) as independent variables was conducted on the mean roughness ratings for the four sandpapers. Mauchly's test of sphericity indicated that the assumption of sphericity has been violated for the independent variable sandpaper roughness, $\chi 2(5) = 13.29$, $p = .021$. Therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .88$). The results showed a significant main effect of sandpaper roughness, $F(2.62, 60.4) = 522.62$, $p < .001$, which indicates that the participants were able to discriminate the four sandpapers according to their roughness (see Figure 2). Post-hoc t-test comparisons with Bonferroni correction showed that participants were able to discriminate between all four sandpapers (all comparisons $p < .001$). There was no significant main effect of chemosensory, $F(2, 46) = 1.60$, $p = .213$. This result suggests that chemosensory did not have an influence on the roughness ratings for the four sandpapers (see Figure 3). The results showed that there also was no significant interaction between chemosensory and sandpaper roughness, $F < 1.0$. This reveals that the profile of ratings across sandpapers of different grit values was not different for the PEA, alcohol or no-odour condition (see Figure 4 and Table 1). Hence, the first hypothesis (H1) that people would judge the tactile surface roughness of objects higher when they are exposed to a substance with a trigeminal component, compared to a no-odour (clean air) condition while touching the objects, as well as the second hypothesis (H2) that people would judge the tactile surface roughness of objects as lower when they are exposed to PEA, compared to a no-odour (clean air) condition while touching the objects, are not supported by these data.

Despite the lack of significance, the ranking of the mean rating responses on roughness in the three chemosensory conditions is in line with our expectations. Participants judged the tactile surface roughness higher when they were exposed to alcohol ($M = 4.23$, *SE*

= 0.163) compared to the no-odour condition *(M* = 4.19, *SE* = 0.147). The results also revealed that people judged the tactile surface roughness of this sandpaper lower when they were exposed to PEA (*M* = 4.04, *SE* = 0.145) compared to the no-odour condition (*M* = 4.19, *SE* = 0.147) (see Figure 3).

We explored whether the effect of PEA on roughness perceptions was different for likers and dislikers of PEA by conducting an independent samples t-test with dependent variable sandpaper roughness in the PEA condition and grouping variable like/dislike PEA. Because the participants rated the pleasantness of the odours on a scale that ranged from 1 = very unpleasant to 9 = very pleasant, we classified the ratings 1-4 as unpleasant (n = 10), the rating 5 as indifferent (n = 1) and the ratings 6-9 as pleasant (n = 13). The mean ratings on pleasantness of the three odours are reported in Table 2. On average, participants rated the tactile surface roughness of the sandpapers in the PEA condition higher when they liked PEA (*M* = 4.15, *SE* = 0.25) than when they did not like PEA (*M* = 3.94, *SE* = 0.19). This difference was not significant, $t < 1.0$.

We explored whether the effect of chemosensory on sandpaper roughness was different for males and females by conducting three independent samples t-tests with dependent variables sandpaper roughness in the three chemosensory conditions and grouping variable gender. On average, females rated the tactile surface roughness of the sandpapers higher (PEA: *M* = 4.33, *SE* = 0.17), (Alcohol: *M* = 4.35, *SE* = 0.18), (No-odour: *M* = 4.40, *SE* = 0.14) than males (PEA: *M* = 3.75, *SE* = 0.21), (Alcohol: *M* = 4.11, *SE* = 0.28), (No-odour: *M* = 4.00, *SE* = 0.25) in all chemosensory conditions. This difference was only significant for the PEA condition, $t(22) = -2.14$, $p = .043$.

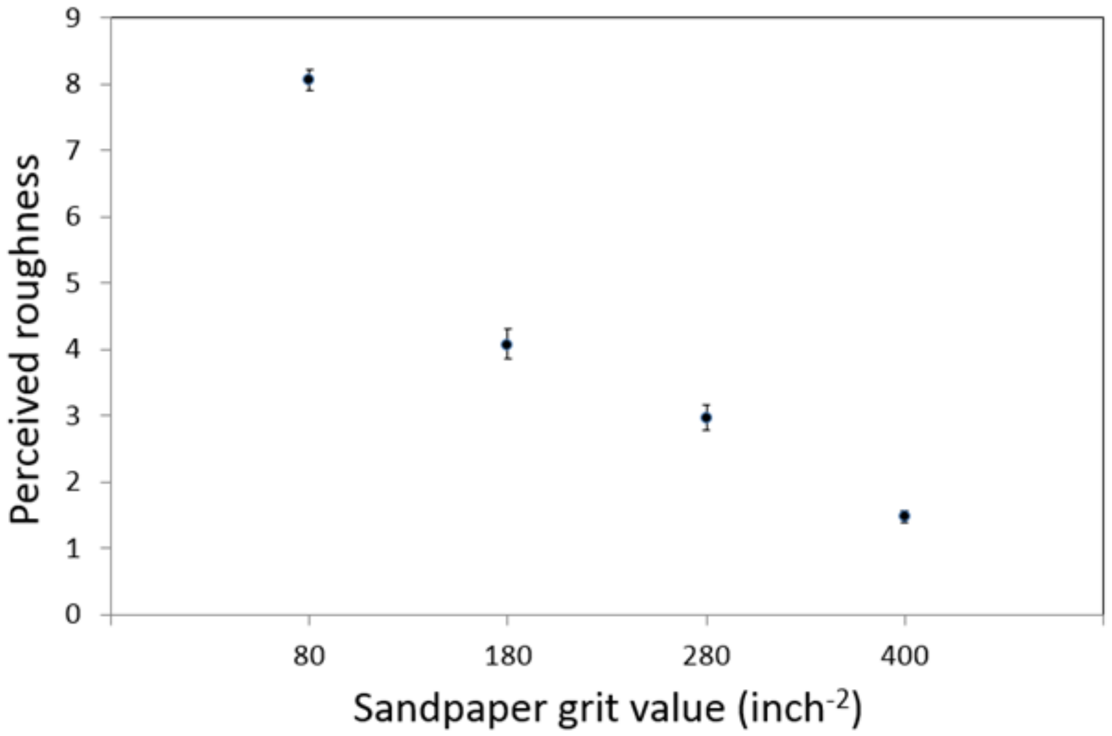

Figure 2. Perceived roughness of four sandpapers with grit value 80, 180, 280 and 400 (the amount of sharp particles per inch^{-2}) on a scale from 1 = least rough to 9 = most rough.

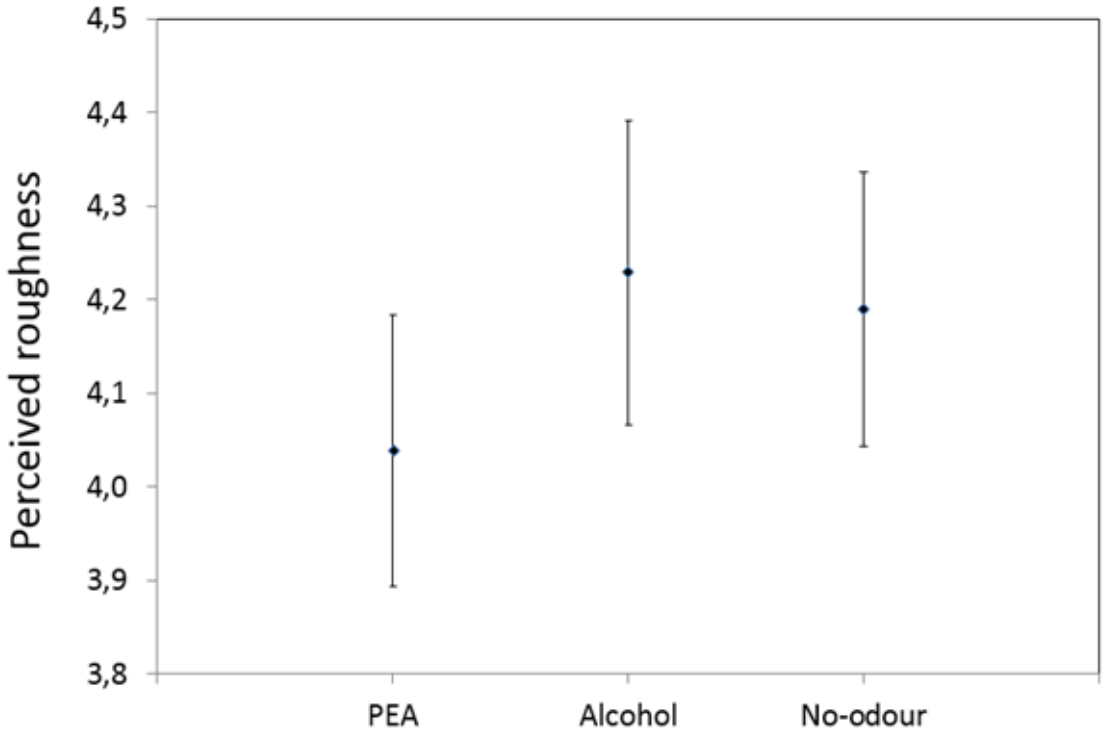

Figure 3. Mean ratings on perceived roughness of the four sandpapers on a scale from 1 = least rough to 9 = most rough in the three chemosensory conditions.

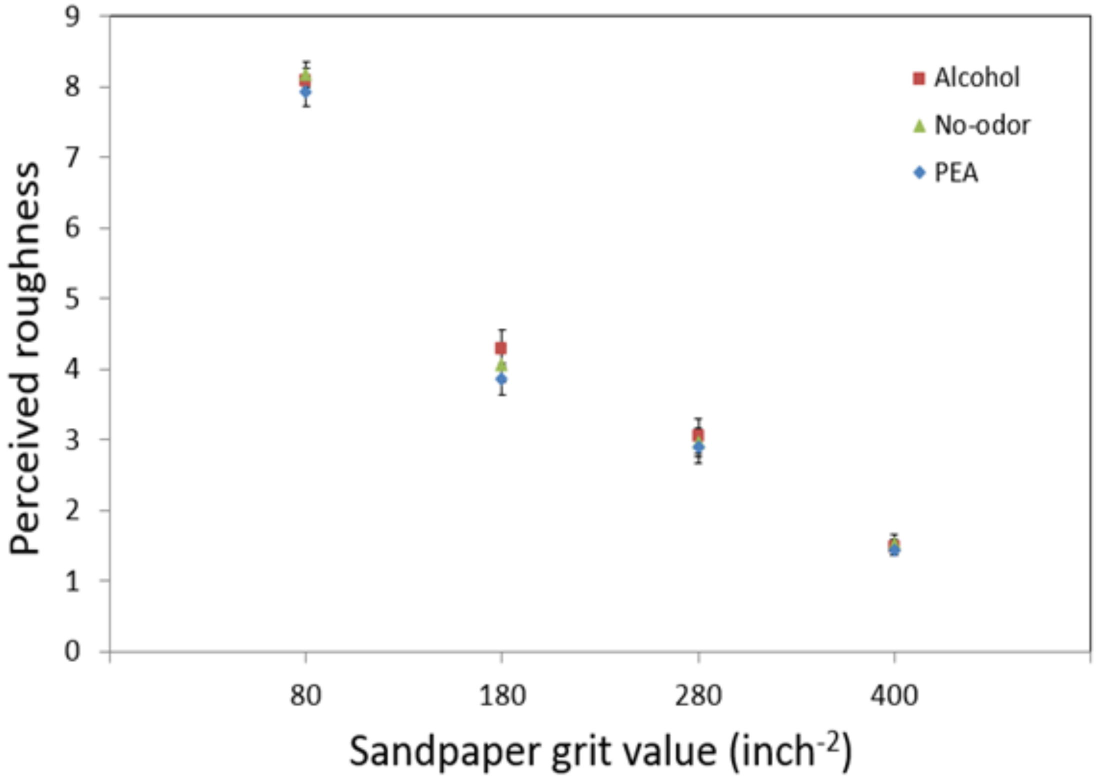

Figure 4. Perceived roughness of four sandpapers with grit value 80, 180, 280 and 400 (the amount of sharp particles per inch^{-2}) in the three chemosensory conditions (Alcohol, PEA and no-odour) on a scale from 1 = least rough to 9 = most rough.

Table 1.

Mean ratings (+SE) of the perceived roughness (1 = least rough, 9 = most rough) of the sandpapers as a function of the grit value and chemosensory.

Chemosensory	Sandpaper Roughness			
	80 [8.07]	*180* [4.08]	*280* [2.98]	*400* [1.49]
PEA [4.04]	7.94 (1.03)	3.86 (1.12)	2.91 (1.10)	1.45 (0.43)
Alcohol [4.23]	8.09 (0.85)	4.29 (1.27)	3.05 (1.17)	1.48 (0.60)
No-odour [4.19]	8.18 (0.84)	4.08 (1.28)	2.30 (0.97)	1.53 (0.64)

The means on perceived roughness per independent variable are reported in square brackets.

Table 2.

Mean ratings (+SE) of the perceived pleasantness (1 = very unpleasant, 9 = very pleasant) and intensity (1 = not detectable, 9 = very intense) for the three chemosensory conditions.

Chemosensory	Perceived pleasantness	Perceived intensity
	Mean	*Mean*
PEA	5.13 (0.52)	7.04 (0.39)
Alcohol	5.88 (0.35)	4.96 (0.46)
No-odour	6.75 (0.36)	2.29 (0.34)

Discussion

In this study we investigated the influence of the olfactory and trigeminal sensation of a chemosensory stimulus on roughness perception. We have chosen for phenylethyl alcohol (PEA) as the olfactory stimulus, alcohol (ethanol) as the trigeminal stimulus and the perceived roughness of four different sandpapers as the dependent measure. We expected that the roughness ratings on the four sandpapers would be affected by the presence of a trigeminal/olfactory stimulus, compared to a no-odour condition. Specifically, we expected that people would judge the tactile surface roughness of objects as higher when they were exposed to a substance with a trigeminal component, and lower when they were exposed to PEA, compared to a no-odour (clean air) condition. Chemosensory substances activate the trigeminal sense, which results in tactile sensations, such as a prickling feeling. We expected that surfaces would feel more rough (which feels like a prickling feeling to your fingers) when simultaneously a trigeminal stimulus was presented, because of the extra tactile prickling the trigeminal stimulus evokes in the nose. We expected that surfaces would feel less rough when simultaneously a rose odour was presented, because rose odour has minimal trigeminal properties and is associated with femininity and softness.

Our results indicated that the participants could discriminate all four sandpapers on basis of their roughness. However, there was no significant main effect of chemosensory condition. The results showed that there also was no significant interaction between chemosensory and sandpaper roughness. Thus our hypotheses were not confirmed.

Despite the lack of significance, the ranking of the mean rating responses on roughness in the three chemosensory conditions was in accordance with our expectations. The results revealed that the mean rating responses on roughness were higher in the alcohol condition compared to the no-odour condition. In contrast, the mean rating response on the roughness ratings were lower in the PEA-condition compared to the no-odour condition.

When we analyzed our results for the roughness ratings on each sandpaper separately, we found the ranking of the mean rating responses on roughness in the three chemosensory conditions was in accordance with our expectations only for the sandpapers with grit value 180 and 280, with the former having the largest difference in ratings. In contrast, the ranking of the roughness ratings in the three odour conditions on sandpapers with grit value 80 and 400 was not in accordance with our expectations, with the ratings being very similar in the three chemosensory conditions. An explanation for this is that the participants often recognized these sandpapers from memory, because they felt both very similar as the extremes on the roughness continuum, i.e. the sandpapers with grit value 60 and 500. In each room the participants first felt the roughest sandpaper (grit value 60) and the softest sandpaper (grit value 500), to create a reference for the ratings 9 and 1. The participants used these sandpapers as anchors during the task. In the actual task the sandpapers with grit value 80 and 400 were difficult to discriminate from the anchors, hence a lot of participants changed their anchors for the ratings 9 and 1 to those sandpapers during the experiment, and automatically rated the sandpapers with grit value 80 and 400 as a 9 or 1.

The sandpapers with grit value 180 and 280 were more difficult for the participants to rate, because they had an intermediate roughness value. Probably chemosensory stimuli have a bigger influence on these roughness ratings, because people were more uncertain about their judgments. Because there was ambivalence, there was room for chemosensory stimuli to influence the evaluations. For further research it may be more effective to include the anchors (e.g. sandpapers with grit value 60 and 500) in the experiment and let the participants rate their roughness as well. Afterwards these ratings can be excluded from further analyses. This may help to remain the anchors in the experiment and to achieve more differences in roughness ratings on the other stimuli. It may also be better to take more levels between the two extremes and the other stimuli, and to exclude the ratings on the two extremes from further analysis, because these ratings are too unreliable.

We do not think that all of the roughness ratings are based on memory, because we asked after the experiment how much sandpapers participants thought they had rated. Almost every participant thought that it were more than 4. We sometimes presented the same sandpaper two times in a row, whereupon participants often answered with another, but comparable rating.

An explanation for the lack of significance may be the concentration of alcohol to which we exposed the participants. For ethical requirements we had to limit the concentration of alcohol. Because the diffuser delivered the alcohol by blowing it into the air of a room of 54 m^3, the alcohol spread quickly and the concentration in the room might be lower than the irritation threshold. It would be better when the concentration had been just above the irritation threshold, because in that manner we could check whether the trigeminal stimulation has worked. We tried to correct for this by blowing the alcohol through a tube into the direction of the participant. During the experiment, most of the participants did not consciously perceive the chemosensory effects. When the participants returned to the alcohol room after the experiment had ended, they rated the intensity of the scent in the room (M = 4.96 on a scale from 1 = not detectable to 9 = very intense). The scent received labels varying from medicine to perfume, with some participants correctly reporting a scent of alcohol. Nevertheless, nobody reported a prickling feeling. Probably the trigeminal stimulation was not intense enough in our experiment to produce a significant effect. When we look back at possible implications for cleaning products, people are exposed to higher doses of alcohol during cleaning than during our experiment. Some people use extensively high amounts of cleaning products and may be very close to the source of alcohol during cleaning. In these amounts and at close approximity, people will feel the prickling feeling of the alcohol in their nose. As earlier described in the introduction, imagine for example the prickling feeling of alcohol in your nose while cleaning the window shield of your car with window cleaner. In our experiment nobody perceived a prickling feeling. For further research on this topic it would therefore be more useful to expose participants directly to the chemosensory in the same concentration and way as during cleaning. For example by letting participants sniff at a bottle or by using an olfactometer.

In the study of Demattè et al. (2006), lemon odour and animal odour were used. The lemon odour was classified as pleasant and the animal odour as unpleasant. The roughness ratings in their study differed significantly in the lemon odour condition compared to the animal odour condition. These two odours thus were extremes on the dimension, 'pleasantness'. We can argue that alcohol and PEA are different on the dimension 'trigeminality', because alcohol appears to be an effective trigeminal stimulus and PEA is known for its minimal intranasal trigeminal properties. The ranking of the mean ratings on roughness in the three odour conditions (i.e. the main effect of odour) is in line with our expectations. This suggests that there may be an effect of these two substances on roughness perception. It is possible that this effect would become significant when two substances are used that are more obvious extremes on the irritation dimension. Using a higher concentration of alcohol will make PEA and alcohol more distinct on their trigeminal properties, which may contribute to a significant effect.

Interestingly, we found a significant effect of gender for the roughness ratings in the PEA condition. Sex-differences were not expected, so this result could be a 'chance-finding'. Women rated the tactile surface roughness higher than men in all conditions (also in the no-odour condition), but this difference was only significant in the PEA condition. The difference in roughness ratings for males and females in all conditions may be due to a greater skin hydration in women than in men. Skin hydration influences the friction between skin and surfaces (Gerhardt et al., 2008). The study of Gerhardt et al. (2008) showed that friction enhances when the skin moisture is higher, but that this effect is significantly higher for women than for men. A better hydrated skin is softer, and therefore will feel more resistance and friction, which results in a rougher perception when the skin is in contact with a surface. Women use more moisturizing crèmes, hence their skin will be better hydrated than men's skin in general. According to Gerhardt et al. (2008) using this kind of crèmes will have a greater influence on skin friction for women than for men as well. This can be an explanation for the higher roughness ratings of women than men in all conditions. However, we tried to correct for this to request participants not to use hand lotion in the morning of the experiment. Nevertheless, the skin hydration of women may be higher than men in general, through more extensive prior use of moisturizing products. To look whether this result is more than a chance-finding, more research on gender differences to the influence of odour on roughness perception is desired.

Because of the lack of significance, the results of this study are difficult to apply in theory and practice. However, the ranking of the roughness ratings in the three chemosensory conditions is interesting. This suggests that the presence of alcohol can make people perceive surfaces as rougher, compared to the presence of no-odour or an odour without a trigeminal component. To find out whether (the trigeminality of an) odour influences roughness perception, a recommendation for further research could be to use two chemosensory substances in concentrations that are more distinct on their trigeminal properties. Using a higher concentration of alcohol could contribute to this, for instance in a study with three chemosensory conditions (e.g. PEA, alcohol and no-odour) in which participants are directly exposed to the chemosensory substances by using an olfactometer or by letting them sniff at bottles. In this manner the alcohol can be presented at the irritation threshold, which makes it more distinct from PEA on its trigeminal properties. Moreover, when alcohol is presented at the irritation threshold it is also possible to check whether the trigeminal stimulation has worked. In this setting there is more certainty about the occurrence of irritation and it will be more visible whether the trigeminal and olfactory sensation of an odour influences roughness perception.

In follow-up studies it may also be more effective to use anchors for the roughness of the surfaces that are more discriminable from the other stimuli (e.g., sandpapers with grit value 40 and 800, which are much more extremes on the roughness continuum and distinct from the other four sandpapers). Including the anchors in the task and letting the participants rate their roughness as well, may help to remain the anchors in the experiment and to achieve more differences in roughness ratings on the other stimuli. Afterwards these ratings can be excluded from further analyses.

For practical implications, it is important that the chemosensory stimuli have to be delivered in the same intensity as during the use of the goal product, in this case cleaning products. If alcohol does have the effect that it makes people perceive surfaces rougher, producers of cleaning products can take this into account. As described earlier in the introduction, this effect may be positive for the efficiency of a cleaning product, if the goal of the producers is to change cleaning behavior. When users perceive the surface rougher while they are cleaning it, they will probably scrub harder to make the surface softer. This will make the surface cleaner which will lead to greater user satisfaction. However, this remains an open question for further research.

Taken together, the results of this study did not show an influence of the trigeminal and olfactory sensation of an odour on roughness perception. Based on the literature we could expect there exist such crossmodal interaction-effects between olfaction and touch. The ranking of the mean ratings on roughness in the three chemosensory conditions in our study was in accordance with our expectations. More research on this topic is therefore desired.

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Appendix A

Plots and images of the roughness of the six sandpapers

Two types of parameters have been calculated for the roughness of the six sandpapers, height parameters and feature parameters. The height parameters are the most commonly used in engineering. These parameters show the amplitude in the surface roughness. The most common height parameter is the Sa-parameter, the “average roughness of a surface”. The feature parameters tell us more on the features on the surface. The most common future parameters are the Spd-parameter, the “number of features” or “density of the peaks”, and the Spc-parameter, the “average curvature of the peaks” or “sharpness”.

In the current study the amplitude (Sa), number of features (Spd), and the sharpness (roundness) of the features (Spc) are important for the tactile properties of the surfaces.

Spc: be aware that the average curvature has mm^{-1} as a unit. The curvature of a peak or summit on the surface is reciprocal of the radius of the summit. A sharp peak has a small radius, yet the curvature is large for a sharp peak (Edwin Gelinck, TNO Eindhoven).

Table A1.

Parameters Sa “average roughness of a surface”, Spd “number of features” and Spc “average curvature of the peaks” for the six sandpapers.

Photo frame	Grit value	Sa	Spd	Spc
1	60	61.93	8.73	38097.3
2	80	43.26	21.25	14858.8
3	180	13.52	33.20	5070.37
4	280	8.49	49.50	1423.32
5	400	7.29	94.76	2523.63
6	500	5.11	83.07	333.25

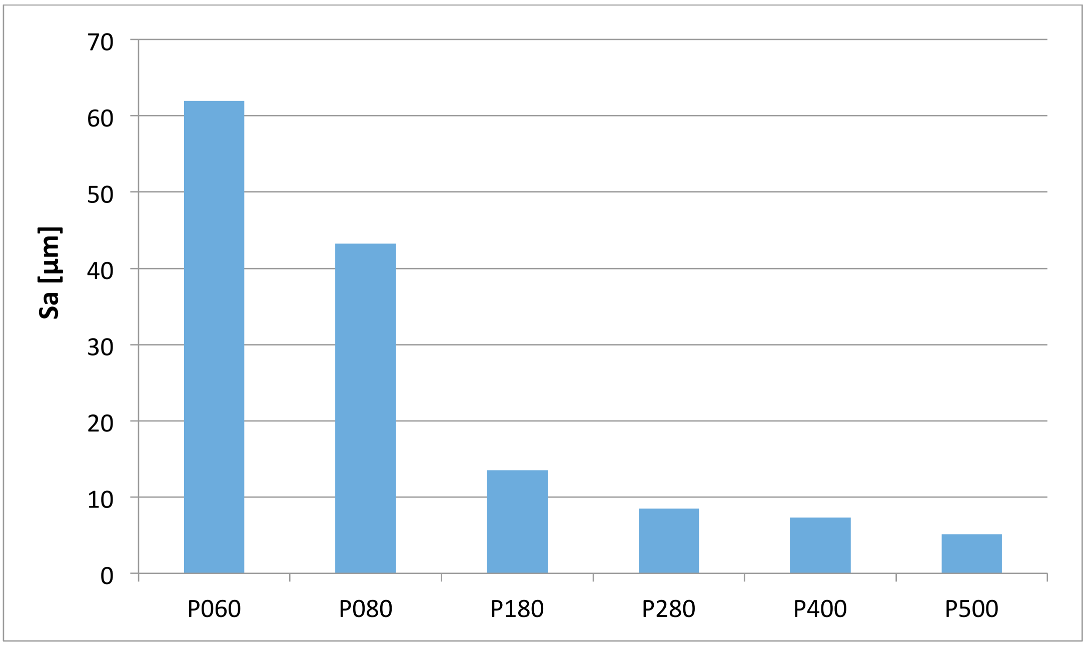

Figure A1. Parameter Sa "average roughness of a surface" for the six sandpapers.

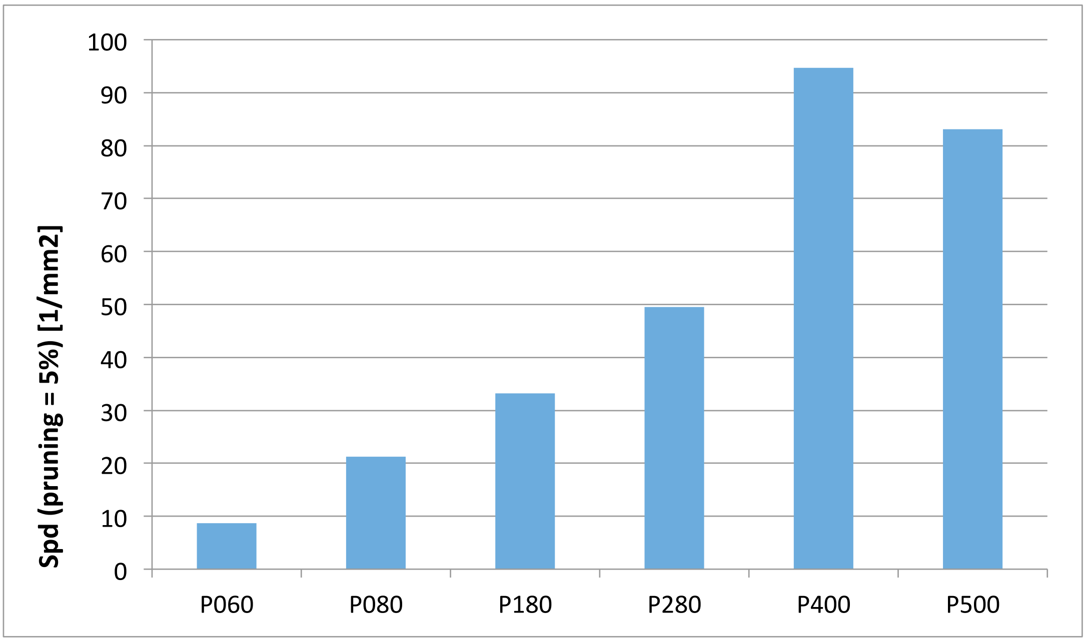

Figure A2. Parameter Spd "number of features" for the six sandpapers.

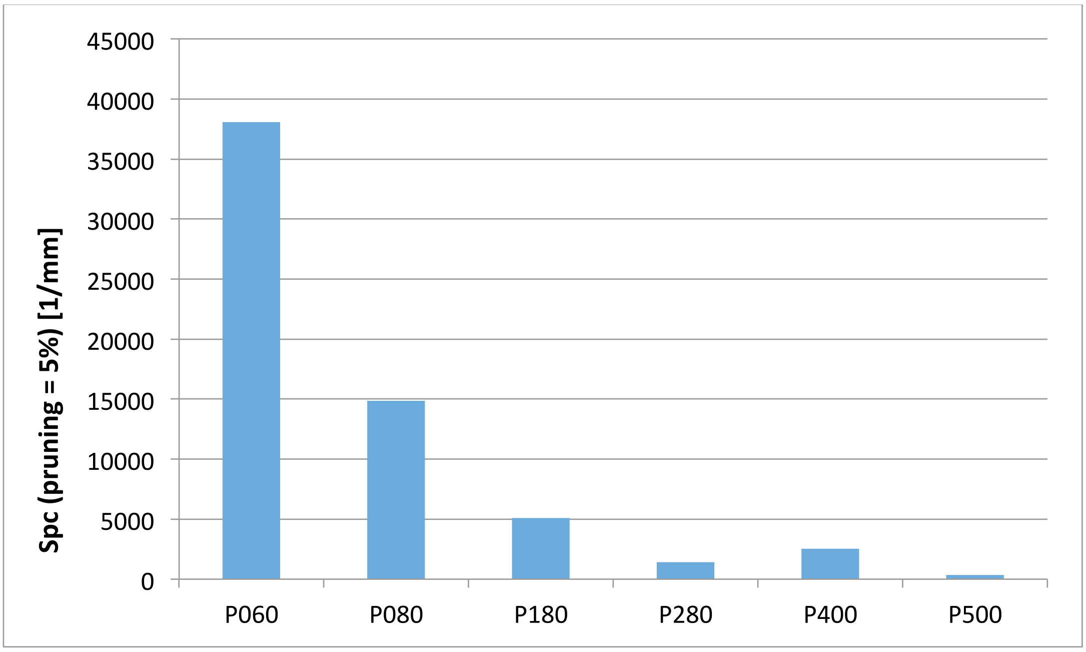

Figure A3. Parameter Spc “average curvature of the peaks” for the six sandpapers.

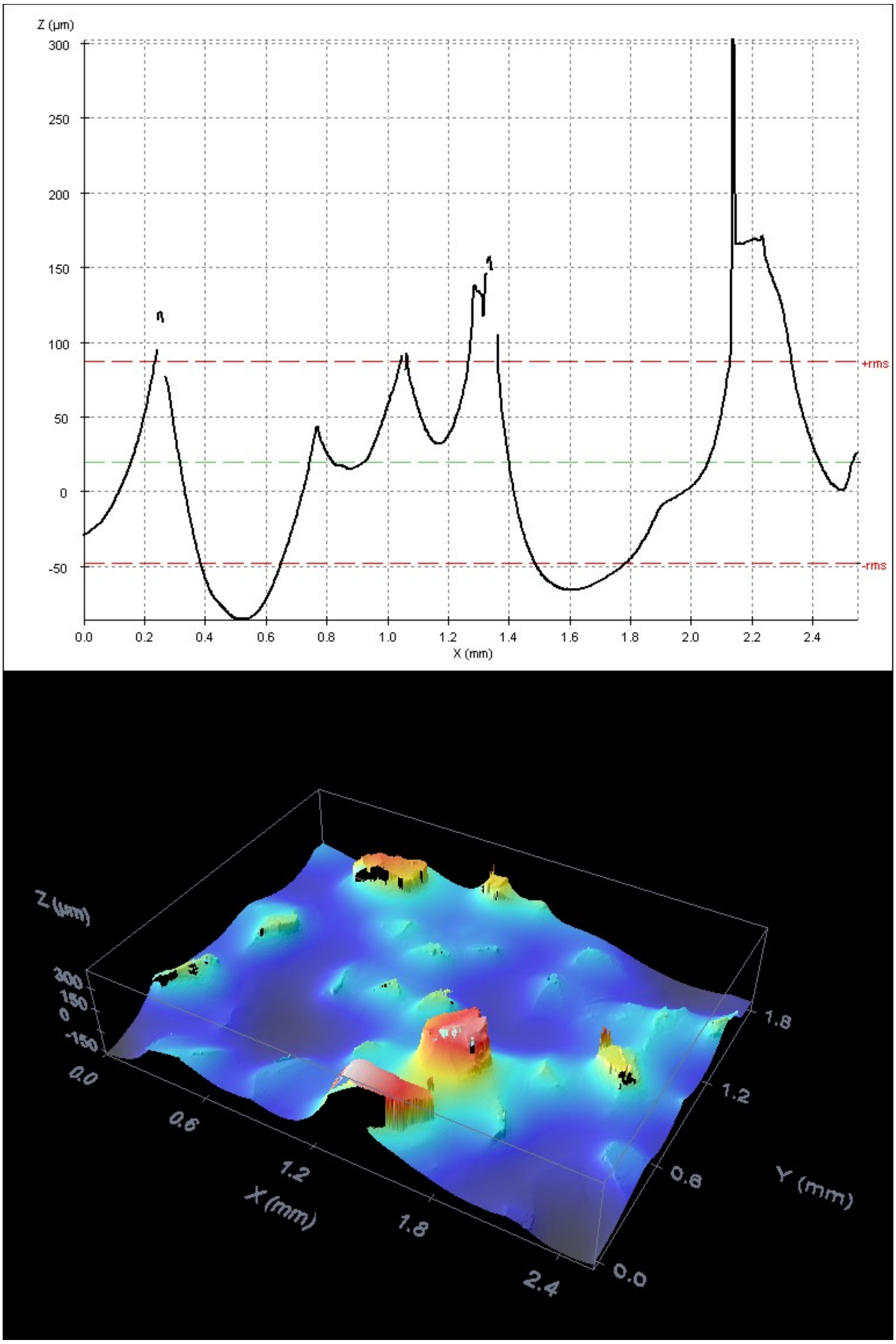

Figure A4. Surface roughness of the sandpaper with grit value 60.

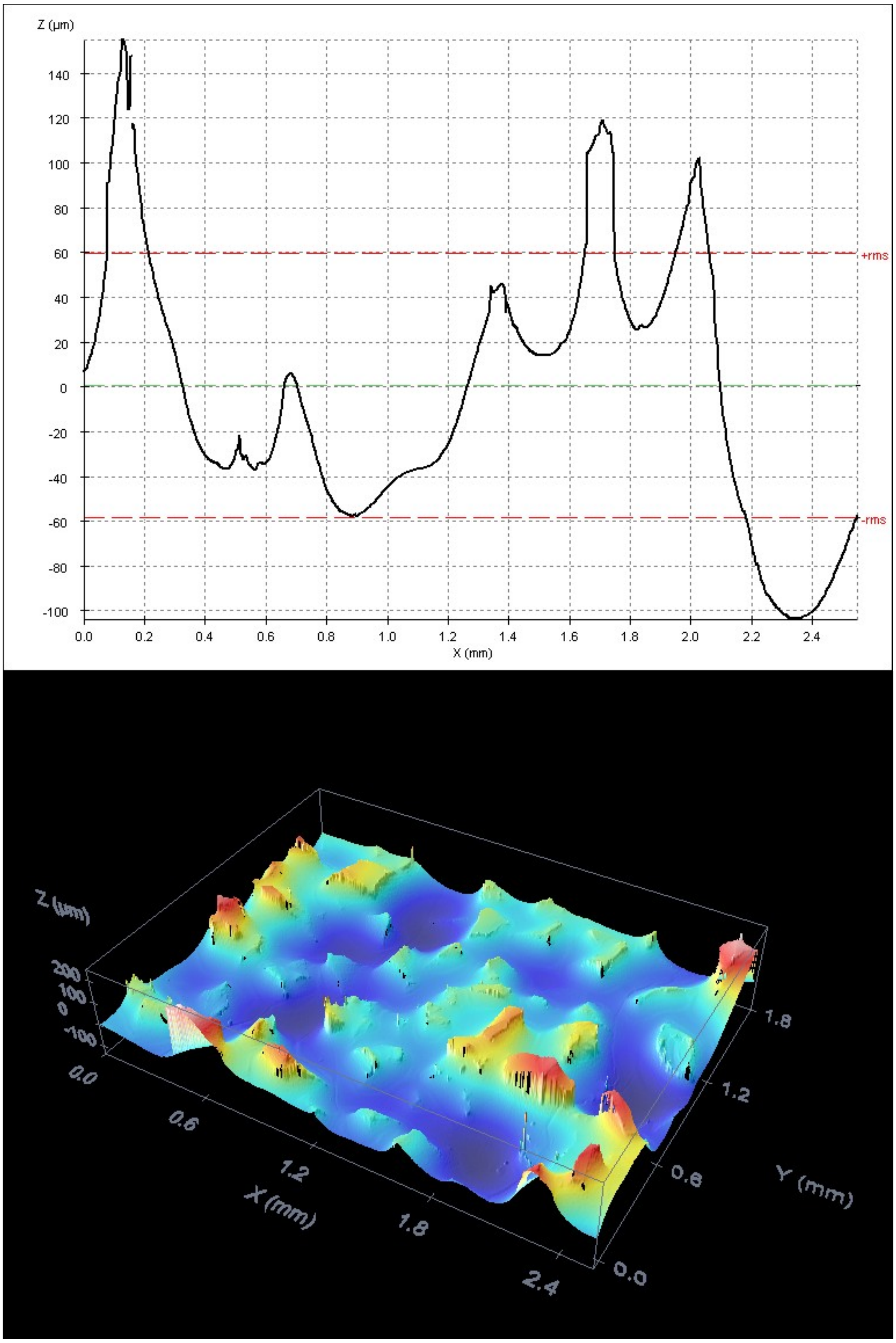

Figure A5. Surface roughness of the sandpaper with grit value 80.

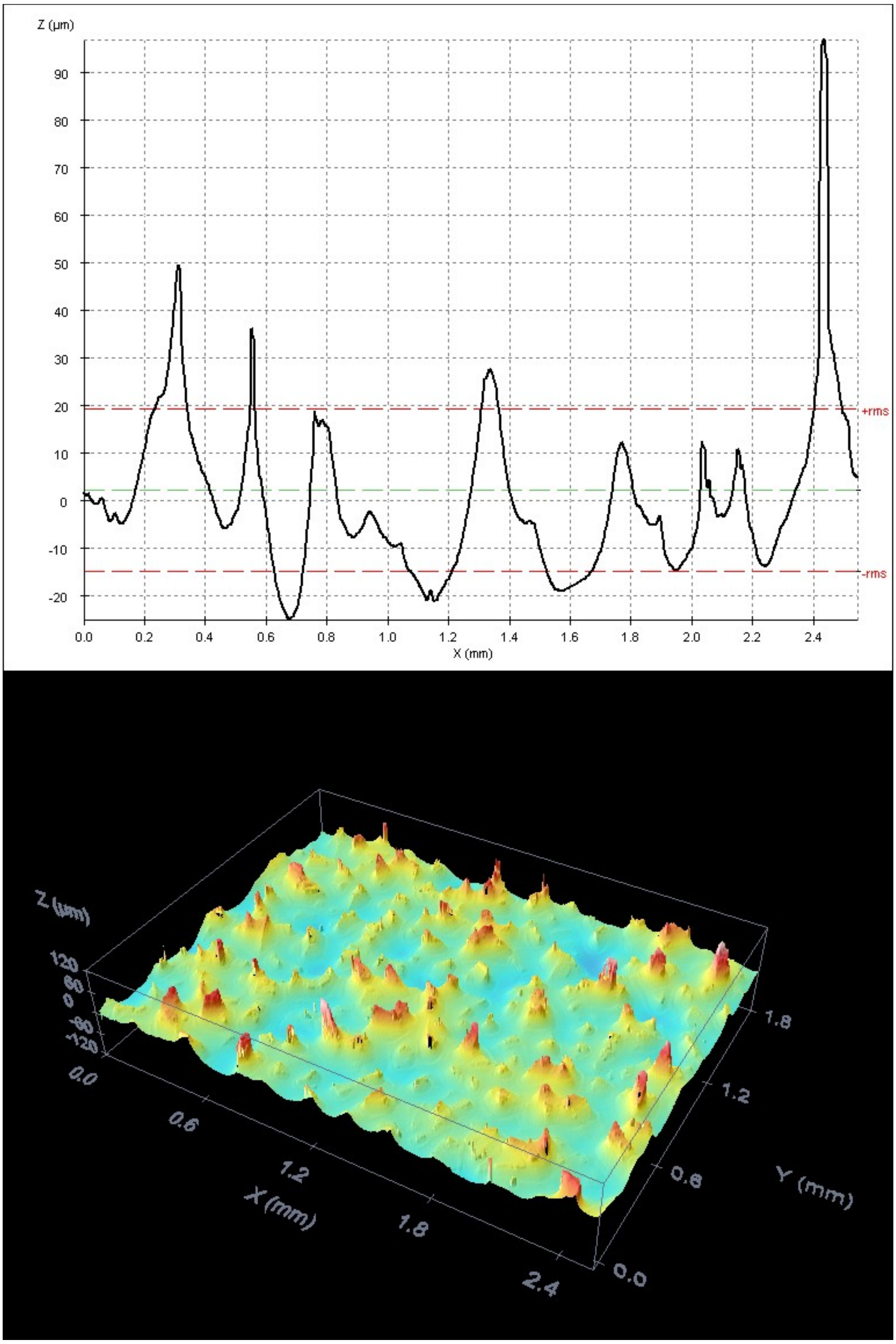

Figure A6. Surface roughness of the sandpaper with grit value 180.

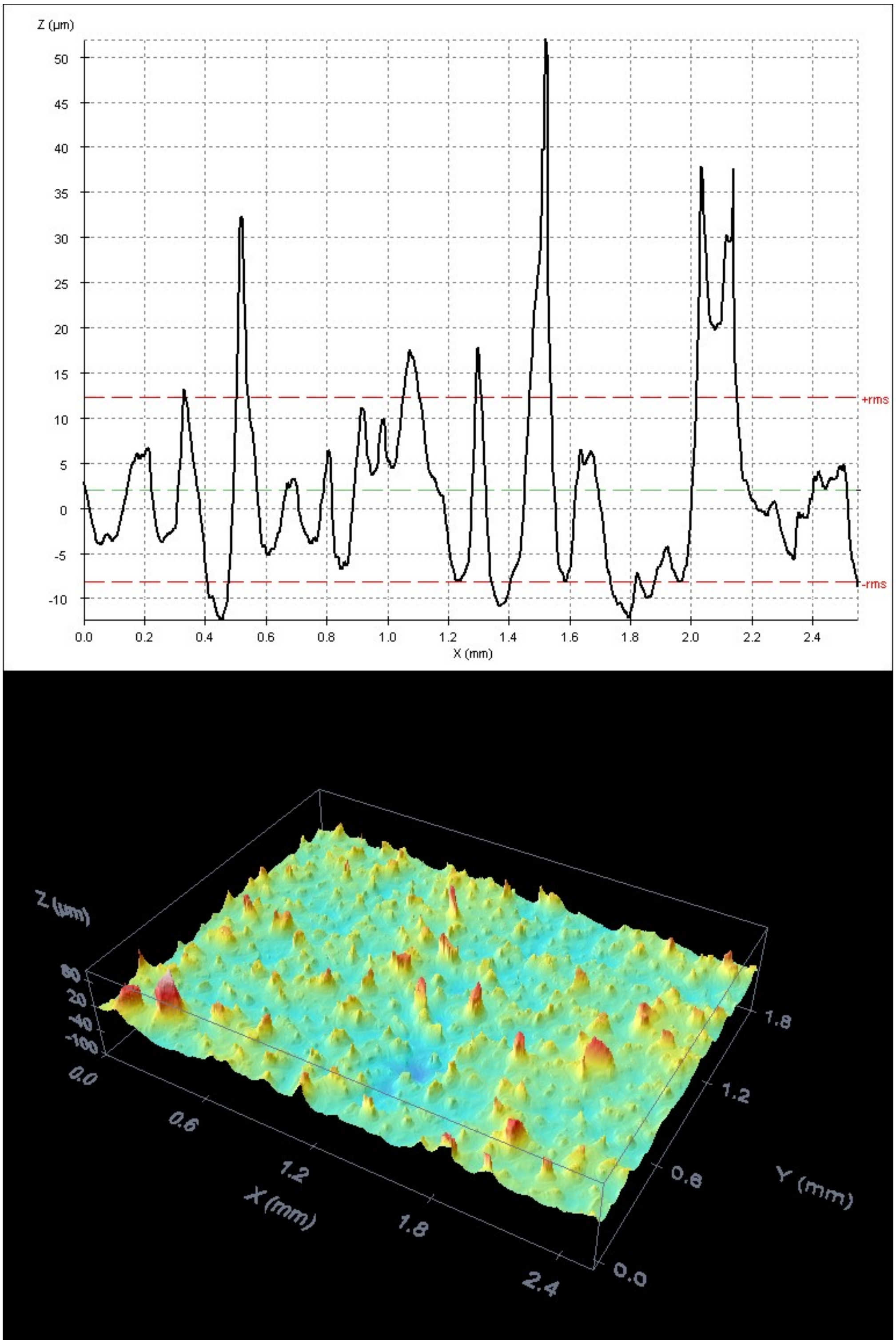

Figure A7. Surface roughness of the sandpaper with grit value 280.

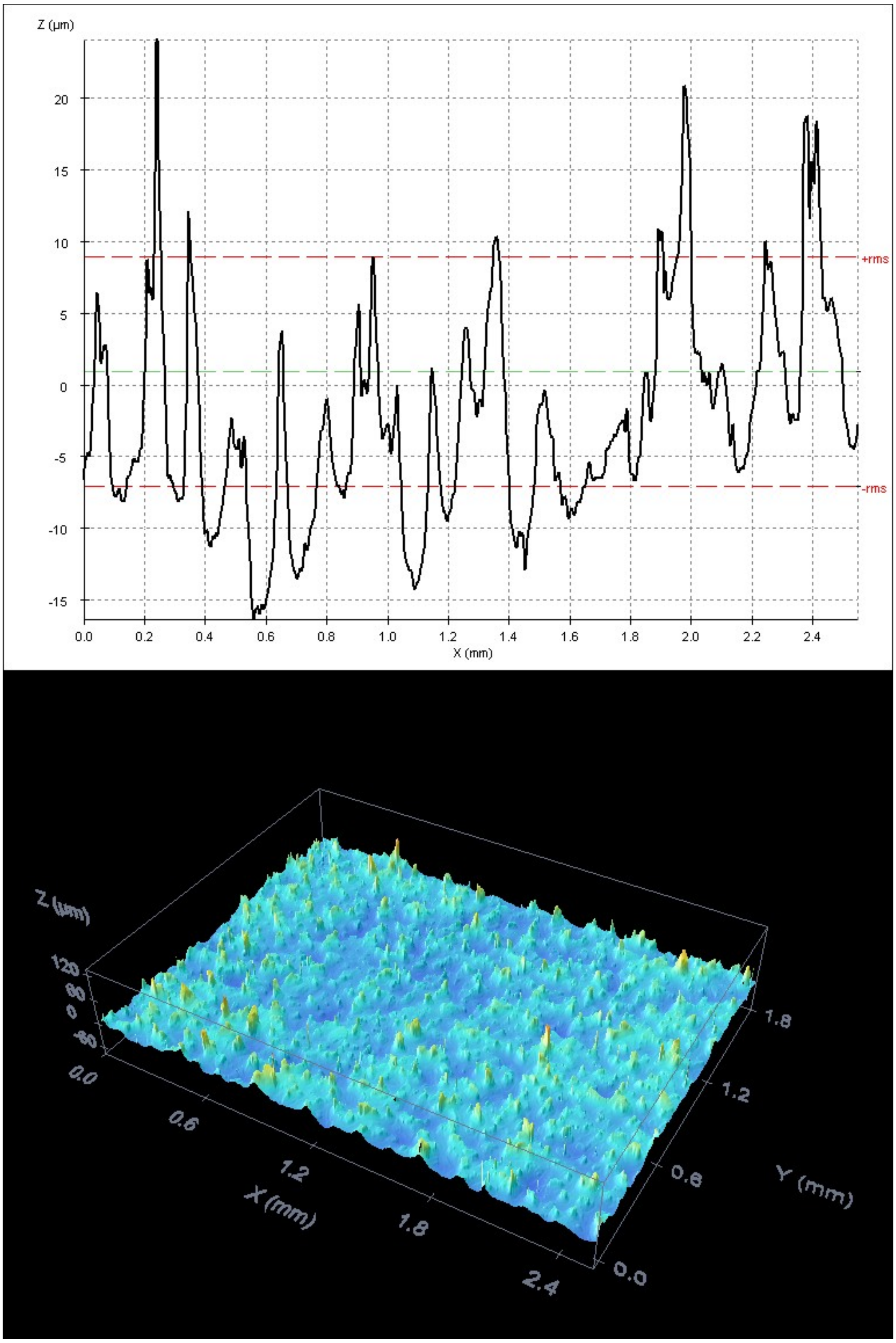

Figure A8. Surface roughness of the sandpaper with grit value 400.

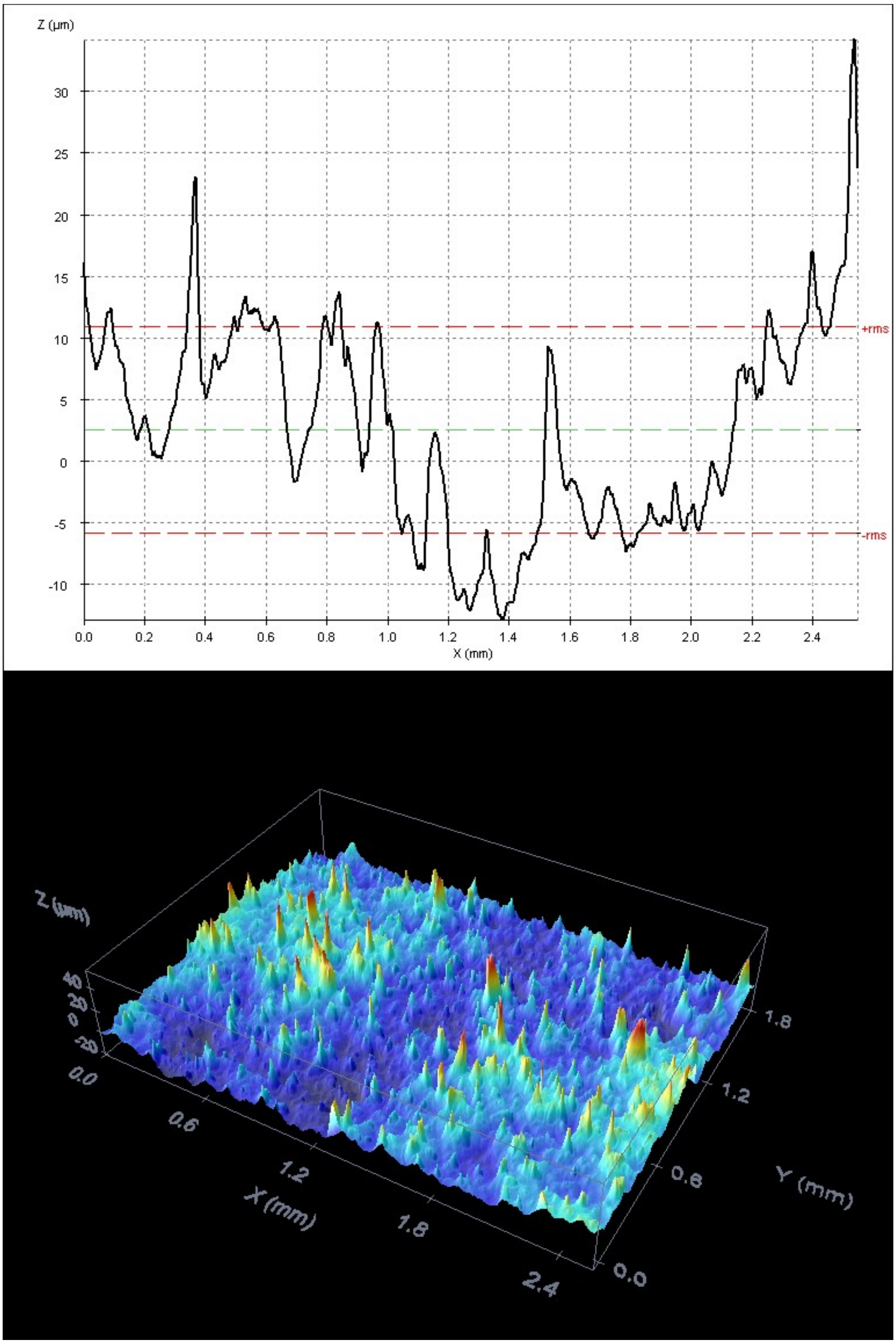

Figure A9. Surface roughness of the sandpaper with grit value 500.

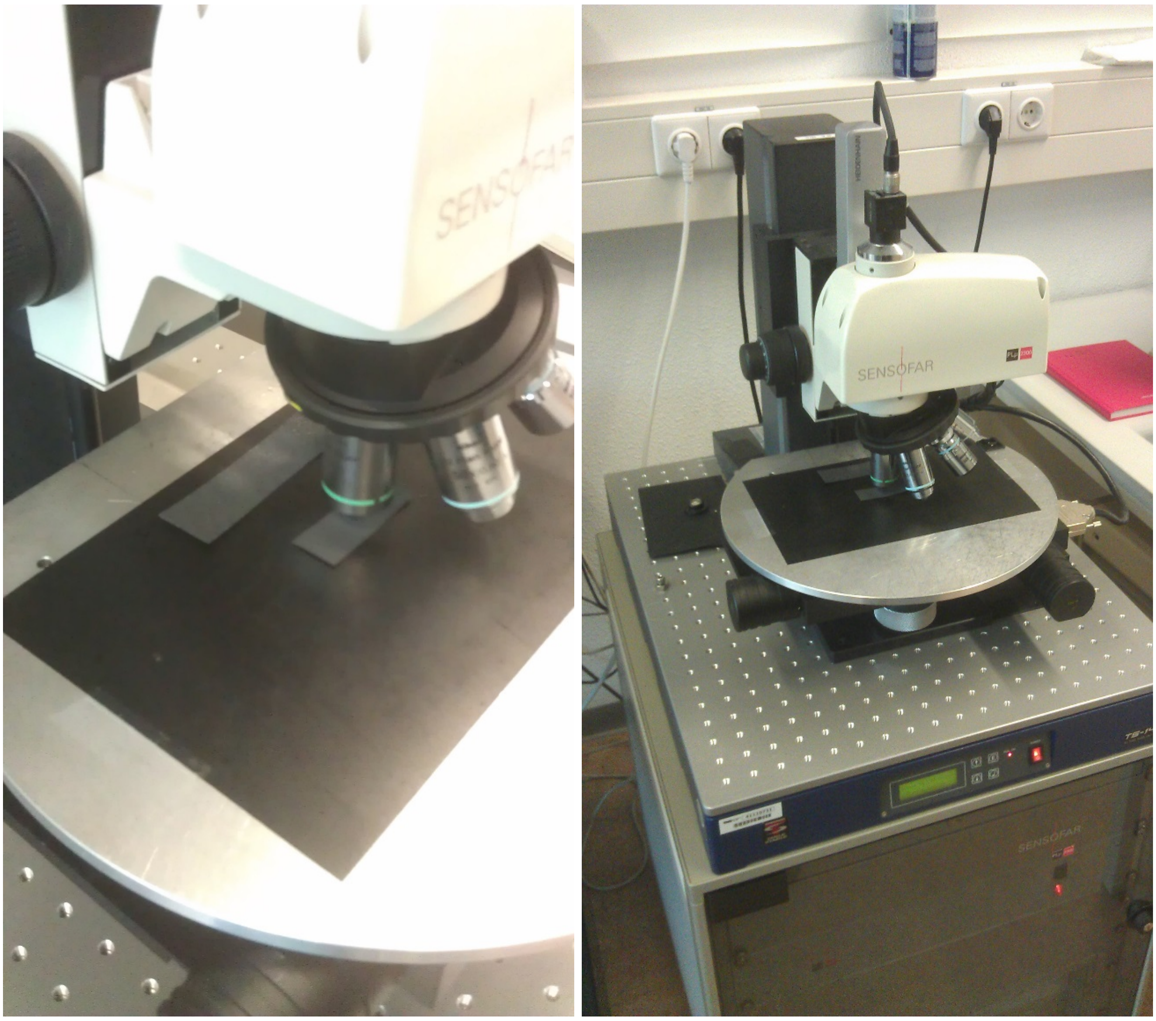

Figure A10. The measurements were taken using the 20x-objective of the Sensofar Optical Imaging Profiler Plμ.

Appendix B

Pictures of the set-up of the experiment

a. The participants read and signed an informed consent and had to put on taped pilot glasses and earmuffs in the waiting room.

b. Three experiment-rooms with ambient odours (PEA, alcohol and no-odour) were located around the waiting room.

c. The experimenter directed the participant into one of the rooms, where they were positioned at a table.

d. The sandpapers were mounted in plastic photo frames of 10x15 cm (grit value: 60, 80, 180, 280, 400 and 500).

e. The participants were instructed to use their preferred hand to feel with their index finger the sandpaper that was presented before them by rubbing their finger on it.

f. In each room an ambient odour (PEA, alcohol or no odour) was delivered by a scent diffuser. The diffusers were located under the table where the participant took place. A tube led the air with the particular odour from the diffuser in the direction of the participant.