Tactile Roughness Perception in the Presence of Olfactory and Trigeminal Stimulants

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Previous research has shown that odorants consistently evoke associations with textures and their tactile properties like smoothness and roughness. Also, it has been observed that olfaction can modulate tactile perception. We therefore hypothesized that tactile roughness perception may be biased towards the somatosensory connotation of an ambient odorant. To test this hypothesis we measured perceived tactile surface roughness in the presence of two different odorants: phenyl ethyl alcohol (PEA), a substance with a rose-like odor and no trigeminal stimulation that is typically associated with softness, and ethanol, a trigeminal odorant with a connotation of roughness. We expected that - compared to a No-odorant control condition - tactile texture perception would be biased towards smoothness in the presence of PEA and towards roughness in the presence of ethanol. However, our results show no significant interaction between chemosensory stimulation and perceived tactile surface roughness. Though not significant, the ranking of the mean roughness ratings in the three chemosensory conditions used in this study agrees with our expectations. This suggests that a crossmodal effect might emerge when tactile stimuli are used that are harder to discrimate (i.e., in conditions of increased rating uncertainty) or when higher odorant concentrations are used. We discuss the limitations of this study and we present suggestions for future research.

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Introduction

When touching an object we perceive its texture not only through cutaneous and thermal input but also by using kinesthetic, auditory, and visual cues (Lederman, 1982). A growing body of research shows that the information processed in one sensory modality is modulated by the simultaneous activation of other sensory modalities (see Driver & Noesselt, 2008, for a review). As a result tactile texture perception can for instance be influenced by audition (e.g., Guest et al., 2002; Jousmäki & Hari, 1998; Klatzky & Lederman, 2010; Lederman, 1979; Werner & Schiller, 1932), vision (e.g., Guest & Spence, 2003a; Guest & Spence, 2003b; Werner & Schiller, 1932), and even olfactory perception (Churchill et al., 2009; Croy, Angelo & Olausson, 2014; Demattè et al., 2006; Gonçalves et al., 2013; Kikuchi, Akita & Abe, 2013).

The inter-modal interaction between touch and vision is for example shown by the fact that bimodal visual and tactile input results in superior roughness discrimination of abrasive papers (Heller, 1982), and that the visual assessment of textile roughness is less accurate in the presence of simultaneously presented incongruent tactile samples (Guest & Spence, 2003b). There is also substantial neuroimaging evidence that vision and touch are intimately connected (for reviews see Amedi et al., 2005; Sathian, 2005; Sathian et al., 2011). Tactile discrimination is to a certain degree mediated by the visual cortex (Lacey, Campbell & Sathian, 2007; Prather, Votaw & Sathian, 2004; Sathian, 2005; Sathian et al., 2011; Sathian & Zangaladze, 2002; Zangaladze et al., 1999). Visual imagery mediates and is essential for some tactile tasks (e.g., orientation discrimination: Sathian & Zangaladze, 2002; Zangaladze et al., 1999).

Evidence for crossmodal interactions between of the tactile and auditory sensing modalities are the observations that people's perception of the roughness of abrasive papers (Guest et al., 2002), the crispness of potato chips (Zampini & Spence, 2004), or even the texture of their own hands (Jousmäki & Hari, 1998) can be modified simply by manipulating the frequency content of the touch-related sounds. Brain studies have shown that the processing of sound in the auditory cortex is modulated by the simultaneous presentation of a tactile stimulus (Kayser et al., 2005), while sound can activate subregions of the medial ventral stream most strongly associated with the visual processing of surface properties of objects (Arnott et al., 2008).

Olfaction can also interact with tactile perception. For example, the perceived smoothness (Demattè et al., 2006) and textural quality (Laird, 1932) of odorized fabrics depends on their odor, lip balm feels smoother with lemon scent than with vanilla scent (Kikuchi, Akita & Abe, 2013), the perceived greasiness and spreadability of cream and gel formulations is influenced by the presence and type of fragrance (Gonçalves et al., 2013), and shampoo fragrance affects the perceived texture of both product and hair (Churchill et al., 2009). Touch pleasantness decreases in the presence of an unpleasant odor (Croy, Angelo & Olausson, 2014). In addition, odors consistently evoke associations with textures and their tactile properties like smoothness and roughness (Spector & Maurer, 2012). Odors can for instance acquire their somatosensory tactile-like qualities during tasting experiences (Stevenson & Mahmut, 2011).

The human nose detects volatile compounds via at least two sensory systems. The olfactory system detects chemicals using specialized receptor neurons distributed on a limited dorsal area of the nasal mucosa and sends signals to the brain via the first cranial (olfactory) nerve. In the nose, mouth, eyes, and other facial areas, the trigeminal system detects chemicals using the more widely distributed free endings of the fifth cranial (trigeminal) nerve. The olfactory system is more dedicated to identification of the hedonic and alimentary aspects of an odorant, whereas the trigeminal system mediates protective functions and reflexes by signaling somatosensory warning signals like cooling, numbness, tingling, itching, burning and stinging. Both systems use overlapping pathways that interact at multiple levels (Rombaux et al., 2013).

Most odorants stimulate both the olfactory and the trigeminal system. Since activation of the trigeminal nerve can evoke haptic sensations it may be regarded as a kind of tactile sense (Lundström, Boesveldt & Albrecht, 2011). Thus, when our nose detects an odorant, we may smell it, feel it, or both. This suggests that olfactory stimulation of the trigeminal nerve could be associated (and thus interfere) with simultaneous tactile perception. In addition, it has also been shown that there are stable semantic crossmodal associations between odors and somatosensory attributes (Stevenson, Rich & Russell, 2012). For instance, a masculine smell is typically associated with a rough texture while a feminine smell is seen as congruent with a smooth texture (Krishna, Elder & Caldara, 2010). It appears that crossmodal odor associations are automatically activated even without conscious odor perception (Seigneuric et al., 2010).

In the present study we investigate the influence of olfactory and trigeminal stimulation on the perception of surface roughness. If olfaction does indeed modulate tactile perception, we expect that the presence of an ambient odorant may bias tactile roughness perception in the direction of its associated characteristics. We therefore measured perceived tactile surface roughness in the presence of two different odorants: a floral odor with no trigeminal stimulation that is typically associated with softness and femininity, and a trigeminal odorant with a rough, sharp or prickly connotation. We hypothesize that compared to a No-odorant (clean air) condition, (H1) tactile texture perception will be biased towards smoothness in the presence of the ambient odorant with a soft or smooth connotation, whereas (H2) tactile texture perception will be biased towards roughness in the presence of the ambient odorant with a rough, sharp or prickly connotation.

In addition to furthering our understanding of multisensory smell-touch interactions, the results of this study may be of interest for the development and evaluation of for instance cleaning products and cosmetics, which typically combine fresh or floral fragrances with trigeminal stimulation from substances such as solvents (e.g., alcohol).

Methods and Materials

Participants

Twenty-four non-smoking participants (12 males, 12 females) ranging in age from 18 to 50 years (mean age 35 years) took part in the experiment. The participants were recruited from the TNO database of volunteers. All participants reported having a normal sense of smell and touch, and no history of olfactory dysfunction. Since smokers are poorer at detecting phenyl ethyl alcohol (used as an olfactory stimulus in this study) than non-smokers (Hayes & Jinks, 2012), we adopted smoking as an exclusion criterion. All participants were naïve to the purpose of the experiment: they were only informed that the study was about roughness perception in the absence of vision and hearing. Participants were requested to refrain from using hand lotion or crème and from wearing scented body lotions or perfumes in the morning of the experiment, since skin hydration significantly affects tactile roughness perception (Gerhardt et al., 2008; Verrillo et al., 1998) and the presence of cosmetic perfumes might interfere with the odorants used in this study. The participants read and signed an informed consent prior to the experiment. The experimental protocol was reviewed and approved by the TNO Ethics Committee and was in accordance with the Helsinki Declaration of 1975, as revised in 2013 (World Medical Association, 2013). The participants received 25 Euros for participating in the experiment, which lasted about 1.5 hours.

Apparatus and materials

The tactile stimuli in this study were samples of sandpaper (3M™ WetorDry™ abrasive paper: see www.3M.com) with six different grades of roughness. The sandpaper grit value (i.e., the amount of sharp particles per square inch) was adopted as a measure for tactile roughness. Lower grit values correspond to higher tactile roughness (Heller, 1982). The grit values of the samples used in this study were respectively 60, 80, 180, 280, 400 and 500 (similar to the range used in previous studies, e.g. Guest et al., 2002; Heller, 1982; Jones & O'Neil, 1985; Rexroad & White, 1988; Stevens & Harris, 1962; Verrillo, Bolanowski & McGlone, 1999). The samples were mounted in rectangular plastic frames with a size of 10×15 cm^2. A pilot study confirmed the results of previous studies that the different grades of sandpaper were indeed discriminable on their perceived roughness. The physical roughness of the six grades of sandpaper was verified by microscopic examination and the surface structure of the sandpaper samples was further assessed by the use of a surface analyzer (a Sensofar PLμ 2300 optical imaging profiler: http://www.sensofar.com).

During the experiments the participants wore both glasses that completely blocked their sight (the glasses were made opaque with black tape) and sound-attenuating earmuffs (BILSOM 717 - 700-

Series, EN 352-1) which reduced the ambient sound by 23 dB. These measures served to eliminate any visual or auditory surface roughness cues and to ensure that participants based their roughness estimates solely on their tactile perception when they rubbed the index finger of their preferred hand across the surface of a sandpaper sample. The sound reduction by the earmuffs was such that that the participants were still able to communicate with the experimenter. The participants' hands were gloved by cotton work gloves, with the index finger of the glove on their preferred hand removed. In this way all participants were restricted to touching the stimuli with the tip of the index finger of their preferred hand.

The trigeminal stimulus was ethanol (73.5% volume percentage, diluted with propyleneglycol or PG). The olfactory stimulus was phenyl ethyl alcohol (PEA, 25% volume percentage, diluted with PG). Ethanol is a largely trigeminal odorant that can cause nasal irritancy at values above the olfaction threshold (Cometto-Muñiz & Cain, 1990; Mattes & DiMeglio, 2001). In contrast, PEA is a substance with a rose-like odor which is only odiferous and has minimal intranasal trigeminal properties (Brand & Jacquot, 2001; Cometto-Muñiz & Cain, 1990; Doty et al., 1978), and which is generally considered pleasant (Khan et al., 2007). Rose-like odors like PEA are typically associated with softness and femininity (Thiboud, 1994), whereas ethanol is often associated with roughness (Demiglio & Pickering, 2008; Jones et al., 2008). All chemical substances were obtained from Sigma-Aldrich (www.sigmaaldrich.com).

The measurements were performed in three separate experiment rooms of equal size (3.5 x 5.5 x 2.8 m^3) and temperature (20 °C), that were shielded from external noise. Each room contained a desk that was covered with a black opaque tablecloth which reached down to the floor. The test solutions were diffused in the rooms through commercial electronic dispensers (small Xenon electric scent diffusers: http://www.scentaustralia.com.au/products/scent-diffuser-xenon.html) that were placed out of sight underneath the desks. A tube led the air with the test solution from the diffuser in the direction of the participant through a small hole in the tablecloth. The tablecloths served as an extra precaution to prevent that the participants could see (even though they wore blindfolds during the experiment) or touch the scent dispensers at any time. Because the earmuffs did not totally eliminate the sound from the diffusers, we recorded their sound and played it at the correct sound level from beneath the desk in the No-odorant condition. This served to ensure that the background noise was similar in all three chemosensory conditions.

Each room was used to present a single odor condition (PEA, Ethanol or No-odorant). The No-odorant (clean air) condition served as a negative control for both the odor (PEA) and trigeminal irritation (Ethanol) conditions (Smeets, Mauté & Dalton, 2002).

Participants judged the perceived tactile roughness of the sandpaper samples using the method of absolute magnitude estimation (AME), a standard technique used in the study of subjective sensation magnitude (Gescheider & Hughson, 1991; Verrillo, Bolanowski & McGlone, 1999; Zwislocki & Goodman, 1980). AME requires participants to match their subjective impression of the size of a number to their impression of the intensity of a stimulus. The participants rated the roughness of the sandpapers on a scale that ranged from 1 (*least rough)* to 9 (*most rough)*. The samples were renewed after every four participants to avoid any impairment of the sandpapers through extended touching.

Odor was intermittently diffused during the experiment (according to a 50% duty cycle with a period of one minute) so that the participants received fluctuating concentrations over time, thus preventing full adaptation. The perceived odor intensity should neither be overwhelming (to avoid eliciting inappropriate expectations in the participants: Elmes & Lorig, 2008; Smeets & Dalton, 2005; see also Loersch & Payne, 2011; Smeets & Dijksterhuis, 2014) nor too low (so that the odor stimulation would be ineffective). Ideally, odor intensity should be above the detection threshold but just beneath the awareness threshold. (The awareness threshold refers to a level of odor at an intensity that someone will only notice it if attention is paid to it.) A pilot experiment was performed to determine a setting of the dispensers and a duty cycle that resulted in a mean rating of 5 on a 9-point scale (from 1 = *not detectable* to 9 = *very intense*). The odor exposure level never exceeded 1900 mg/m^3 (1000 ppm, as determined with a MiniRAE 3000 photoionization detector, see www.raesystems.com) in accordance with the recommended limit for one hour exposure conditions as given by the Health Council of the Netherlands (Dutch Expert Committee on Occupational Standards, 2006). The room in which the test was performed was well ventilated prior to each session.

The instructions and the response scale which the participants could use to report their judgments were verbally explained by the experimenter at the start of the experiment. During the tasks the participants verbally reported their judgments, and the experimenter registered the responses on a response sheet.

Experimental design and analysis

We used a mixed design ANOVA to analyze the perceived roughness scores with gender as between-subjects and chemosensory (PEA, Ethanol and No-odorant) and sandpaper roughness (grit values 80, 180, 280 and 400) as within-subjects independent variables. The experiment consisted of three blocks of 48 trials (four trials of four sandpapers for each of the three chemosensory conditions). The presentation of the four sandpapers in the three chemosensory conditions was randomized, just as the presentation of the chemosensory conditions themselves. All statistical analyses were performed with IBM SPSS 20.0 for Windows (www.ibm.com). For all analyses a probability level of $p<.05$ was considered to be statistically significant.

Procedure

After their arrival at the laboratory, the participants were welcomed in a central waiting room that was surrounded by the experiment rooms. Here they first received a verbal introduction and instruction from the experimenter, after which they read and signed an informed consent form. Participants were informed that they would be repeatedly estimating the perceived tactile roughness of paper surfaces. The participants were then blindfolded and asked to put on the earmuffs and gloves. The experimenter then guided them to one of the three rooms. The participant and the experimenter both took place on opposite sides behind the desk. On each trial the experimenter placed a sandpaper sample on the table directly in front of the participant.

In each chemosensory condition the participants were first presented with the roughest sandpaper sample (grit value 60) and the smoothest sample (grit value 500), to enable them to build up a reference for the task ahead. No roughness ratings were given for these two samples.

When exploring the stimuli with their preferred hand, all participants were instructed to hold each panel by its edges, using the non-preferred, gloved hand. They estimated the magnitude of the perceived stimulus roughness by moving the uncovered index fingertip of their preferred gloved hand back and forth with a moderate force and velocity over approximately 4-6 cm of the sample surface. The participants were allowed to repeatedly examine a sample surface before indicating its roughness. The speed of hand movement was not controlled in this experiment, since perceived roughness is largely independent of scanning velocity when actively exploring a surface texture with the bare finger (Lederman, 1983; Lederman, 1974; Yoshioka et al., 2011).

In each chemosensory condition the participants rated the roughness of all four samples in a randomized order. Each sample was presented four times in four trials per chemosensory condition. Every 30 seconds the next sample was presented, to ensure that each participant spent the same amount of time in each chemosensory condition. A full run in each condition lasted 10 minutes.

After each run, the participants were led back to the waiting room for a 5-minutes break. During the break they removed their glasses and earmuffs and read a magazine. They could also drink some water if they wanted. The 5-minute break after each run served to minimize carry-over effects from one chemosensory condition to the next 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 in another chemosensory condition. Hence, the participants performed exactly the same task in each chemosensory condition. After the third and final run, the participants were guided back to the waiting room where they removed their glasses and earmuffs. Then they filled out a demographic questionnaire and they were asked whether they had noticed anything particular in the environment during the three runs. Finally, the participants were directed for the last time into each of the three rooms (this time with their eyes and ears open) and they were asked to rate the intensity and pleasantness of the odor in each room on scales ranging from 0 (*not detectable* / *very unpleasant*) to 9 (*very intense* / *very pleasant*). See Figure 1 for a schematic representation of the entire experiment.

Results

Figure 2 shows the mean perceived roughness of the four sandpapers for each of the three chemosensory conditions (PEA, Ethanol, No-odorant). On first inspection the ranking of the mean roughness ratings in the three chemosensory conditions appears to agree with our expectations. Compared to the perceived roughness in the No-odorant condition ($M = 4.19$, $SE = 0.147$), participants judged the tactile surface roughness of the sandpaper samples higher when they were exposed to ethanol ($M = 4.23$, $SE = 0.163$) and lower when they were exposed to PEA ($M = 4.04$, $SE = 0.145$). Further inspection of the data shows that the ranking of the mean roughness ratings in the three chemosensory conditions was in accordance with our expectations for the sandpapers with grit values 180 and 280, with the former having the largest difference in ratings (see Figure 3). The difference between the mean roughness ratings in the three chemosensory conditions was minimal for sandpapers with grit values 80 and 400, and the ranking for these ratings did not agree with our expectations.

A mixed-design ANOVA with *gender*, *chemosensory condition* and *sandpaper roughness* as independent variables was conducted on the mean roughness ratings over the four repetitions. The results indicate that the roughness ratings did not differ between males and females: $F(1, 22) = 2.40$, $p = .14$; power with α set at .05 was .32. Previous studies consistently failed to find any significant differences between males and females in sensitivity thresholds for PEA (Segal et al., 1995; Stevens & O'Connell, 1991; Zatorre & Jones-Gotman, 1990) and in olfactory and irritation thresholds for ethanol (Mattes & DiMeglio, 2001). Our present results are in accordance with these previous findings. The results showed a significant main effect of sandpaper roughness, $F(3, 66) = 537.06$, $p < .001$. A post-hoc Tukey HSD test showed that participants were able to discriminate between all four sandpapers (all comparisons $p < .001$). There was no significant main effect of chemosensory condition, $F(2, 44) = 1.61$, $p = .21$. This suggests that chemosensory condition did not affect the roughness ratings for the four sandpapers. The results also show that there was no significant interaction between chemosensory condition 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, Ethanol and No-odorant conditions. Hence, both hypothesis H1 (people judge the tactile surface roughness of objects higher when they are exposed to a substance with a trigeminal component compared to a No-odorant or clean air condition) and hypothesis H2 (people judge the tactile surface roughness of objects as lower when they are exposed to PEA, compared to a No-odorant or clean air condition) are not supported by our data.

The mean ratings on *pleasantness* and *intensity* of the three chemosensory conditions are listed in Table 1. The perceived pleasantness was near neutral (between 5.13 and 6.75) in all conditions. The perceived intensity varied from almost imperceptible (2.29) in the No-odorant condition, via near neutral (4.96) in the Ethanol condition to intermediate (7.04) in the PEA condition. The scent predominantly received floral labels in the PEA condition (16 out of 24). The Ethanol condition also evoked distinct associations in most participants (21 out of 24) ranging from *medicine* (7 out of 16) to *perfume* (2 out of 24), with some participants correctly reporting a scent of alcohol (7 out of 24). Most participants (14 out of 24) did not have any association in the No-odor condition, while some gave labels like *musty* (2 out of 24) or *nature* (5 out of 24). The fact that the participants consistently rated the intensity higher in the odorant conditions than in the No-odorant condition, predominantly reported a floral odor in the PEA condition, and reported appropriate associations in the Ethanol condition (i.e., substances that may contain alcohol like medicine and perfume), while no one reported noticing a smell during the experiments, suggests that the odorants were successfully administered at near awareness threshold levels.

In principle, odors of different hedonic value may differentially affect perceived roughness. Therefore we explored the effects of PEA on roughness perceptions separately for likers and dislikers of PEA by conducting an independent samples t-test with *sandpaper roughness* as the dependent variable in the PEA condition and *(dis)like PEA* as the grouping variable. Because the participants rated the pleasantness of the odors on a scale from 1 (*very unpleasant*) to 9 (*very pleasant*), we classified ratings 1-4 as unpleasant (n = 10 dislikers), rating 5 as indifferent (n = 1), and ratings 6-9 as pleasant (n = 13 likers). 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 ($M = 3.94$, $SE = 0.19$). However, this difference was not significant, $t < 1.0$.

Discussion

We investigated the influence of ambient chemosensory stimuli with different roughness connotations on tactile roughness perception. Thereto we measured the perceived tactile roughness of sandpapers with four different grades of surface roughness, in conditions with respectively clean air (control or No-odorant condition) and phenyl ethyl alcohol (PEA) and ethanol as ambient odorants.

We expected that compared to a No-odorant control condition, tactile texture perception would be biased towards (H1) smoothness in the presence of PEA since this odorant is typically associated with softness and femininity, and (H2) towards roughness in the presence of ethanol since this odorant has a rough connotation due to its trigeminal nature.

We found no significant main effect of chemosensory condition on perceived surface roughness. The results showed that there also was no significant interaction between chemosensory stimulation and sandpaper roughness. Thus both our hypotheses (H1 and H2) were not confirmed.

Despite the lack of significance, the ranking of the mean rating responses on roughness in the three chemosensory conditions agreed with our expectations. The results revealed that the mean roughness ratings were higher in the Ethanol condition and lower in the PEA-condition compared to the No-odorant condition. Further analysis of the roughness ratings for each type of sandpaper individually showed that the ranking of the mean roughness ratings in the three chemosensory conditions was in accordance with our expectations only for the sandpapers with grit values 180 and 280, with the former having the largest difference in ratings. The variation in the roughness ratings for sandpapers with grit values 80 and 400 was minimal in the three chemosensory conditions and their ranking did not agree with our expectations. The consistency and small variation in the responses for the stimuli with the highest and lowest grit values may be due to the fact that the participants often recognized these stimuli from memory as being the extremes used in the actual test set and gave them corresponding extreme ratings (9 or 1). This may be because the sandpapers with grit values of respectively 60 and 500 (the extremes used in the actual tests) were difficult to discriminate from sandpapers with the absolute extreme grit values of respectively 80 and 400 which the participants used as anchors to construct their internal reference scale prior to each run. In the experiments the participants may have changed their prior anchors (grit values 60 and 500) for the extremes of the subjective roughness scale (ratings 9 and 1) to the extreme grit values that actually occurred during a test (grit values 80 and 400) thereby automatically assigning them extreme ratings. In a debriefing after the experiment we also asked the participants how much different types of sandpapers they thought they had rated during the actual tests. Most participants thought they had rated more than the 4 different types that were actually presented. In some tests we presented the same sandpaper two times in a row, whereupon participants often answered with a different but comparable rating. This indicates that not all roughness ratings were based on memory.

If chemosensory stimuli can affect roughness ratings, this will most likely occur when people are uncertain about their tactile judgments. In the present study the sandpapers with grit values 180 and 280 were more difficult for the participants to rate because of their intermediate roughness values. This ambivalence may have left room for chemosensory stimuli to influence the evaluations. Future studies should probably include even more different roughness levels and exclude the extremes from further analysis to achieve a higher sensitivity.

An explanation for the lack of significance of the results from the ethanol condition may be that the concentration to which the participants were exposed was too low to produce a noticeable physiological effect. For ethical reasons the ethanol concentration was limited in this study to the awareness threshold (Health Council of the Netherlands, 2006). As a result the concentration in the room was below the irritation threshold so that most of the participants did not experience any chemosensory effects. The participants rated the intensity of ethanol as intermediate ($M = 4.96$ 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. These findings suggest that we successfully administered ethanol at a just noticeable level. However, nobody reported a prickling feeling.

Demattè et al. (Demattè et al., 2006) observed significant differences between roughness ratings in odor conditions that were extremes on the dimension, ‘pleasantness’. Their participants rated fabric swatches as feeling significantly softer when presented with a lemon (pleasant) odor than when presented with an animal-like (unpleasant) odor. It can be argued that ethanol and PEA are extremes on the dimension ‘trigeminality’, because ethanol is an effective trigeminal stimulus and PEA has minimal intranasal trigeminal properties (PEA is typically considered a negative control for irritation: (Smeets, Mauté & Dalton, 2002). The fact that the ranking of the mean roughness ratings in the three odor conditions (i.e., the main effect of odor) is in line with our expectations suggests that there may indeed be an effect of trigeminality, which may become significant when two substances are used that are more obvious extremes on the irritation dimension.

Previous studies that found crosssmodal interaction effects between olfaction and touch used naturalistic tactile stimuli like textile samples (Demattè et al., 2006; Guest & Spence, 2003b; Laird, 1932), cream and gels (Gonçalves et al., 2013; Kikuchi, Akita & Abe, 2013) or shampoo and hair (Churchill et al., 2009) which all have good ecological validity and do not abrade the skin of the perceiver, unlike the abrasive papers used in the present study. Hence, it would be interesting to repeat this study with for instance pilled cotton swatches with different degrees of pilling (Guest & Spence, 2003b).

Summarizing, although previous studies observed crossmodal interaction between olfaction and touch, the present study showed no effect of trigeminal and olfactory stimulation on tactile roughness perception. Though not significant, the ranking of the mean roughness ratings in the three chemosensory conditions used in our study agrees with our expectations. This suggests that a crossmodal effect might emerge when a wider range of just discriminable tactile stimuli are used, possibly in combination with a higher odorant concentration or with odorants of that are more obvious extremes in the trigeminal spectrum. More research on this topic is therefore still required.

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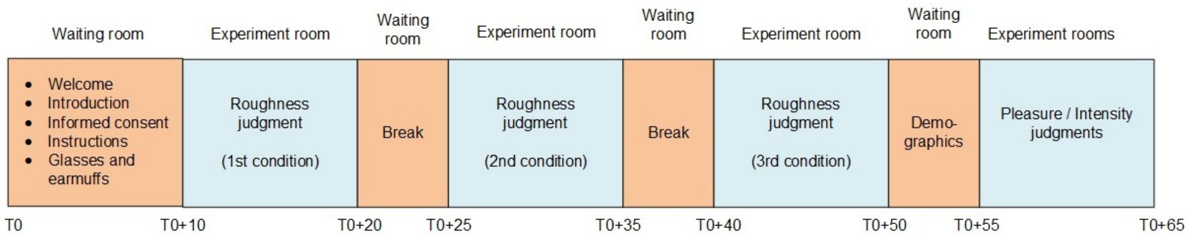
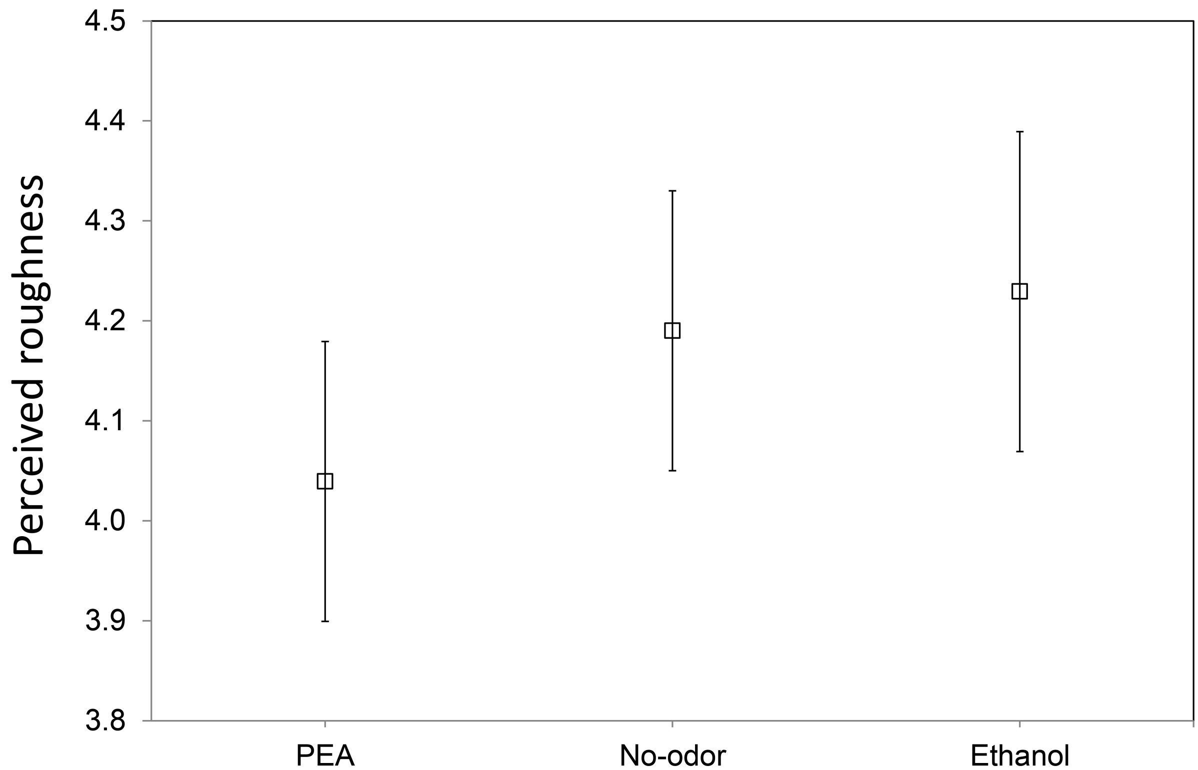
519 **Figures**



520 Figure 1. Schematic representation of the procedure.



521 Figure 2. Mean perceived roughness of the four sandpapers on a scale from 1 (*least rough*) to 9
522 (*most rough*) for each of the three chemosensory conditions (PEA, Ethanol, No-odorant).

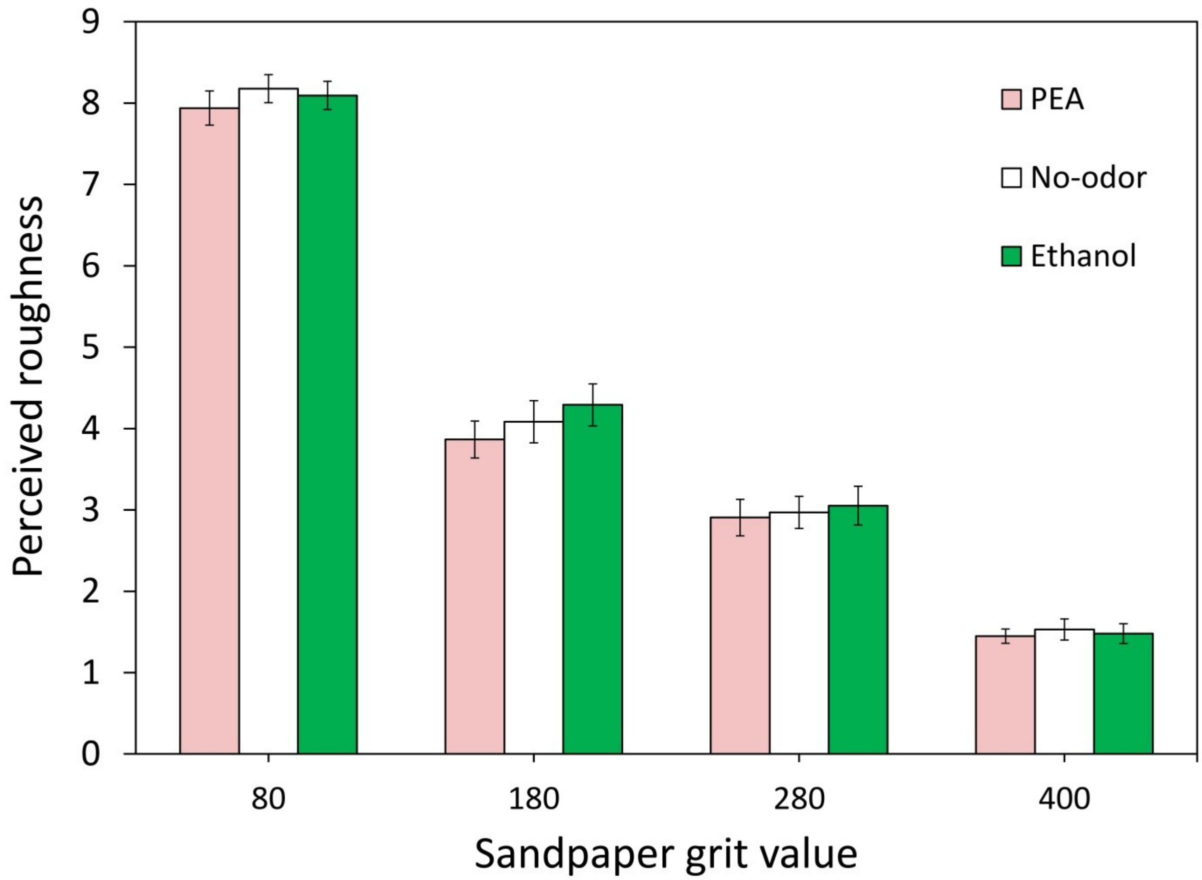


Figure 3. Mean perceived roughness of sandpaper with grit values 80, 180, 280 and 400 (the numbers correspond to the approximate amount of sharp particles per square inch) in the three chemosensory conditions (PEA, Ethanol and No-odorant) on a scale from 1 (*least rough*) to 9 (*most rough*).

Tables

Table 1. 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 condition	Perceived pleasantness	Perceived intensity
PEA	5.13 (0.52)	7.04 (0.39)
Alcohol	5.88 (0.35)	4.96 (0.46)
No-odorant	6.75 (0.36)	2.29 (0.34)