The Influence of Surface Roughness and Surface Size on Perceived Pleasantness

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2023 IEEE World Haptics Conference (WHC) | 979-8-3503-9993-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/WHC56415.2023.10224384

Abstract— **Objects' material properties are essential not only in how we use and interact with them but also in eliciting affective responses when in contact with the body. Such affective experiences are of particular interest because they likely strongly impact our daily interactions with materials. We examined whether exploration time and surface size could influence affective responses to rough stimuli. Here, participants made pleasantness and arousal judgments after actively exploring sandpaper stimuli of different sizes with varying roughness levels under different time constraints. Findings confirm that increased surface roughness is associated with decreased perceived pleasantness; however, arousal did not systematically covary with roughness. We didn't find an effect of exploration time on perceived pleasantness or arousal, but there were interactions between grit size and surface size. Overall, the direction of the effects of grit size on pleasantness was similar for both surface sizes. However, the slopes of increase in pleasantness relative to grit size varied depending on surface size. Effects on arousal were unrelated and small. We suggest that exploration time had little influence on the perceived magnitude of affective reactions to roughness. However, surface size may influence not only perceived roughness but also the perceived pleasantness of rough stimuli.**

Keywords—roughness, pleasantness, arousal, haptic perception, surface properties

I. INTRODUCTION

Humans are very apt at perceiving and identifying material properties of objects in an instant, which is vital in determining their potential usage and guiding our subsequent behaviours. For example, we press on the surface of fruits to determine their ripeness or rub the fabric between our fingers to assess whether a garment would be comfortable. However, the material properties of objects are essential not only in how we use and interact with them but also in eliciting affective responses when in contact with the body. Affective experiences likely impact our daily interactions with materials in terms of approach/ avoidance behaviours. Different materials can induce different affective sensations when touched, depending on their physical attributes [1-2]. For instance, while smooth and soft materials tend to evoke pleasant sensations, rough and rigid materials such as sandpaper and brick would typically elicit unpleasant sensations [3-7]. Here, we study how temporal and spatial presentation factors modulate the link between roughness and unpleasantness.

Roughness is arguably one of the most salient and well-studied dimensions of tactile perception. Roughness relates to the spatial structure and unevenness of a material's surface. Prior studies have examined the physical factors contributing to roughness perception and manipulated surface roughness by varying the local features of the surface, such as width, height, shape, and spatial characteristics of gratings [e.g. 8-10] or raised dots [e.g. 11-14]. These studies indicated that the spatial distribution of physical elements heavily influences roughness perception (e.g., bumps, dots, gratings) of a given surface. The magnitude of perceived roughness increased as the elements' spacing widened.

Although most research to date has focused on the influence of local features of surfaces on roughness perception, recent evidence highlighted the potential relevance of global features on roughness perception. For example, [15] investigated the influence of surface curvature and dot spacing on perceived roughness using 2D raised dots patterns on sinusoidal-like curve surfaces with varying numbers of cycles/curves. Their findings demonstrated that, regardless of the direction of finger movements, the spacing between raised dots and the number of cycles significantly influenced the magnitude of perceived roughness, and observers judged the surface with more curves to be rougher, especially when the dot spacing was large. This observation suggests a link between global features and roughness perception. However, the extent to which global features influence roughness perception and, potentially, by extension, the experience of pleasantness (i.e., Valence) remains unclear.

Previous research has investigated the relations between roughness and pleasantness by varying the local physical characteristics of material surfaces and measuring how these variations affect observers' perceptual judgements and affective responses. For example, [6] used a wide range of items varying in their sensory properties (e.g. sandpaper, leather, marble) and had participants rate the materials according to their pleasantness. Findings indicated that observers rated smooth and soft items to be more pleasant to touch than rough and sticky materials, and fingertip moisture level was found to modulate the perceived pleasantness of materials. [4] had participants explore sandpapers of various grit values before estimating the magnitude of perceived roughness and pleasantness of the surface explored. Results showed that the magnitude of perceived pleasantness negatively correlated to the magnitude of perceived roughness (smaller grit values associated with higher roughness levels): The rougher a surface felt, the more unpleasant it was perceived to be. Similarly, [16] found that the magnitude of perceived unpleasantness increased with increased roughness; the magnitude of unpleasantness was also greatly influenced by the speed at which the surface was moved relative to the skin. Overall, these observations reveal the link between the perception of roughness and (un)pleasantness and that increasing roughness is associated with increasing unpleasantness.

Further studies have investigated factors beyond physical surface characteristics that mediate the relationship between material properties and pleasantness. In particular, it has been found that passive stimulations produce more heightened affective responses than active explorations, in which pleasant stimuli were judged to be more pleasant when they were received passively, and unpleasant stimuli were perceived as more unpleasant when explored actively [1, 17]. Also, physical factors such as force and velocity have been shown to contribute to the perception of pleasantness, in which unpleasant stimuli were perceived to be more unpleasant when a greater force was exerted during explorations, and stimuli moving at a lower velocity were judged to be more pleasant than those moved at a higher velocity [18, 5, 19-20].

Overall, the literature demonstrated that unpleasantness is linked to roughness and that additional factors contribute to and modulate the relations between material properties and pleasantness. In this study, we aimed to examine how temporal and spatial presentation factors, in particular surface size and exploration time, influence the relationship between roughness and pleasantness perception. We speculate that surface size is a global feature that could influence perceived roughness similar to surface curvature—be it via shared processing pathways or via higher-order factors [15, 21]. Additionally, we speculate that prolonged exploration may amplify the perception of unpleasant roughness characteristics, leading to a greater feeling of discomfort. (cf. [1]). This aligns with findings from a recent study [22], which suggest that the affective processing of unpleasant auditory stimuli occurs within a few seconds, and full emotional effects unfold after 3 seconds. This suggests rapid processing of affective stimuli. Consequently, we aimed to investigate the impact of exploration duration (2 vs. 3 seconds) on participants' perception of pleasantness, with a minimum exploration duration of 2 seconds to allow sufficient time for active exploration.

Moreover, thus far, studies investigating the affective reactions to touched materials mainly focused on pleasantness. However, material qualities might not only evoke pleasantness but also induce other affective responses [23]. Here, we also measure the arousal elicited by our surfaces, where arousal refers to the subjective state of feeling activated or deactivated, being a continuum from a very calm state/sleepiness (low) to vigilance/excitement (high). Our stimuli consisted of micro grain sandpaper of seven grit sizes, with particle size ranging from 7 to 25.8μm. Each grit size of sandpaper was cut into circles of five different sizes to create 35 grit size-surface size combinations. Under different time constraints (2 vs 3s), the participant's task was to freely explore the material surface with a finger before rating the pleasantness and arousal of the surface explored.

II. METHODS

A. Participants

Fifteen participants (3 males, Mage = 25.60yr, SDage = 3.22yr, Range: 22-33yr) were recruited from Giessen University. Our sample size was similar to those of previous studies examining roughness and/or pleasantness perception using sandpaper as stimuli (e.g., [1, 3, 4, 7, 29]; N = 8-16). All participants were right-handed and had no history of motor or cutaneous impairments. All participants had a 2-point discrimination threshold of < 4mm on their right-hand fingertips. All participants provided informed consent and received compensation of (8€/h) for their participation. This study was approved by the ethics committee at Giessen University (LEK FB06) and conducted in accordance with the declaration of Helsinki (2013).

B. Stimuli and Apparatus

Participants sat at a table opposite the experimenter. A monitor and keyboard were placed on the participants' left, and a curtain was placed on their right side. Noise-cancelling headphones (Sennheiser HD 4.5 BTNC) were used to eliminate any unwanted sounds from the surroundings and sounds that may be generated from the explorations of material surfaces and present beep sounds to indicate the start and end of a given exploration period. The curtain was placed between the participant and experimenter, which allowed participants to put their arms through to explore the stimulus whilst blocking their view of their hands and the stimulus presented to them.

The stimuli consisted of assorted commercially available micrograin sandpapers of seven grit sizes, 600 (25.8 ± 1μm), 800 (21.8 ± 1μm), 1000 (18.3 ± 1μm), 1200 (15.3 ± 1μm), 2000 (10.3 ± 0.8μm), 2500 (8.4 ± 0.5μm) and 3000 (7μm), the values in parenthesis indicate the particle size [24]. Smaller grit values are associated with increasing levels of roughness. A pilot study was conducted to determine the minimum and maximum surface sizes suitable for active touch with a single finger, and five diameter sizes ranging from 4 to 8 cm were chosen. Each grit size of sandpaper was cut into circles of five different sizes (diameter: 4/5/6/7/8 cm) to create 35 grit size-surface size

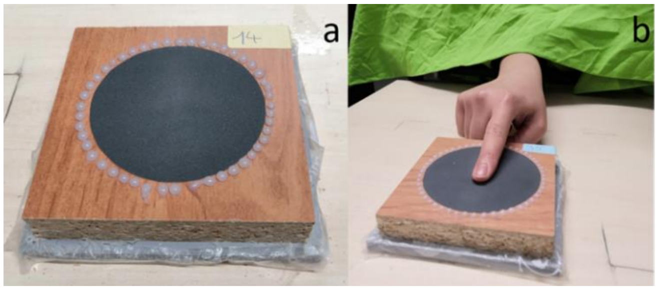

Fig.1. Depiction of experimental set-up and stimuli used in the experiment.

M.C. and K.D. were supported by Deutsche Forschungsgemeinschaft DFG-project no. 502774891-ORA project "UNTOUCH" and European Union's Horizon 2020 FET Open research program under grant agreement no 964464 (ChronoPilot). L.L. and K.D. were supported by the Hessisches Ministerium für Wissenschaft und Kunst (HMWK; project 'The Adaptive Mind')

combinations. Each of these samples was fixed to the centre of a wooden block (10cm ×10cm × 2cm) and surrounded by a border made of plastic dots (see Figure 1a). Each of these samples was placed in a custom-made 3D-printed shallow tray mounted on the table behind the curtain (see Figure 1b). To minimise potential habituation after an extended period of material surface explorations, a wooden block wrapped in a plastic sheet was presented to participants every five trials in both the practice and test blocks. Participants were instructed to explore its surface and rate it in terms of its pleasantness and arousal, like in other trials, but the responses were not recorded. All material stimuli (sandpaper surfaces and plastic-covered block) were cleaned after each use and replaced regularly.

C. Design and Procedure

In two sessions, participants completed two exploration time conditions (2s vs 3s), the order of which was counterbalanced across participants. Participants completed the two sessions on two consecutive days, each taking approximately 50 minutes. Each timing condition consisted of two blocks: practice and test. In the practice block, each of the 35 grit size-surface size combinations was presented once in a randomised order to familiarise participants with the different surface size and grit size combinations (5 surface sizes, 7 grit sizes). In the test block, each grit size-surface size combination was randomly presented four times (i.e., 140 trials). Participants completed a total of 175 trials in each timing condition. Fingertip moisture levels were not measured in the current experiment as we have employed a within-subject design, and all trials were fully randomised. Hence, should there be any influences arising from individual differences/ fluctuations in fingertip moisture levels, it would be consistent across conditions.

After providing their informed consent, participants were asked to sit facing the table, and we assessed the 2-point discrimination thresholds. Afterwards, they were given instructions for the proper experimental task and encouraged to ask any questions. Participants were told that they would be exploring some material surfaces but were not given explicit instructions on how to explore them to avoid bias in participants' exploration strategies. Instead, they were instructed to freely explore the material surfaces in any way they saw fit, as long as they were exploring using a single finger and within the exploration time limit given . Once they understood the task, the participants put their arms through the curtain, and the first trial began. On a given trial, participants were presented with a stimulus behind the curtain. They would first hear a beep sound that signals the start of the exploration, and participants then explore the material surface with their right index finger. Then, they would hear a second beep indicating the end of the exploration. The exploration duration was limited to 2 or 3 seconds. Following their exploration, the participant's task was to rate the pleasantness and arousal of the stimuli explored on a 7-point Likert-type scale.

The questions and associated Likert scales are as follows:

Pleasantness - "*Wie angenehm/unangenehm hat sich das Material für Dich angefühlt?* (How pleasant or unpleasant did the material feel to you?).": 1 = *sehr unangenehm* (very unpleasant) , 7 = *sehr angenehm* (very pleasant).

Arousal - "*Wie aufregend war es für Dich das Material zu erfühlen*? (How arousing was it for you to feel the material?): 1 = *überhaupt nicht aufregend* (not arousing at all), 7 = *extrem aufregend* (extremely arousing).

Next, participants were instructed to make their ratings using a number keyboard. Once they had made their ratings, the subsequent trial began, and a new stimulus was presented to the participant.

III. RESULTS

Two participants were excluded from the analysis as they failed to complete both experimental sessions. Responses from the practice block were not included in the analysis, and the remaining 140 trials from each participant were analysed. To analyse the influence of exploration time and surface size on pleasantness and arousal ratings, we conducted two repeated measures ANOVAs with exploration time (2 seconds and 3 seconds), grit size (600/800/1000/1200/2000/2500/3000), and surface size (4/5/6/7/8 cm) as within-subjects variables, and the pleasantness or arousal as the dependent variable. Greenhouse-Geisser correction [25] is applied whenever the sphericity assumption is violated. Initial exploratory data analyses demonstrated that even with normalisation, the patterns of results did not differ; hence, raw ratings were used for all subsequent analyses.

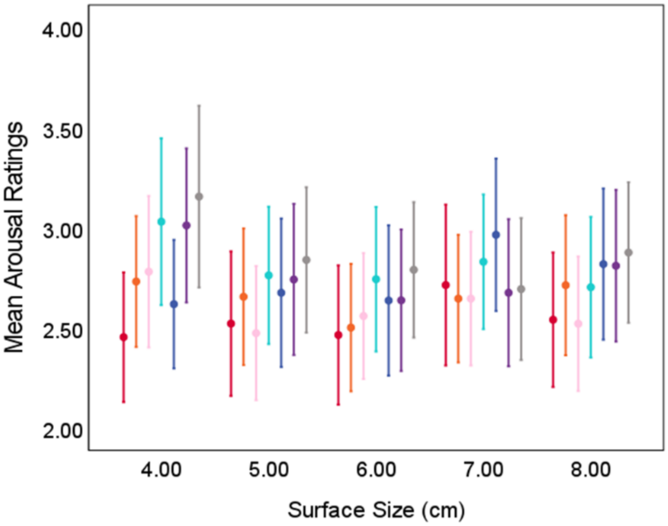

Fig. 2. Mean perceived arousal as a function of surface size. Error bars represent 1±SE. Each colour corresponds to a grit size: red = 600; orange =800; pink =1000; teal =1200; navy =2000; purple =2500; grey =3000.

Arousal. We found no effects of exploration time on arousal ratings, $F(1, 12) = 0.00$, $p = 0.99$, $\eta p^2 = 0.00$, nor an effect of grit size on arousal ratings, $F(6, 72) = 1.41$, $p = 0.22$, $\eta p^2 = 0.11$. We found effects of surface size, $F(4, 48) = 2.66$, $p = 0.04$, $\eta p^2 = 0.18$. Bonferroni-corrected post hoc tests between each pair of surfaces sizes showed that, in particular, participants found the surface size with a diameter of 7cm ($M = 2.73$, $SE = 0.33$) to be more arousing than those with a diameter of 6cm ($M = 2.62$, $SE = 0.33$, $p = 0.03$). There were no other significant differences ($p = 0.24 - 0.99$) in these post hoc tests (see Figure 2). Further, we found an interaction between grit size and surface size, $F(24, 288) = 1.77$, $p = 0.02$, $\eta p^2 = 0.13$, in that some of the stimuli of certain grit size were perceived to be more arousing depending on their surface sizes, see Table 1 for significant interactions between grit size and surface size on arousal ratings.

Table 1. Significant interactions between grit size and surface size on perceived arousal.

Grit Size	Surface Size						
		M	*SE*		*M*	*SE*	*P*
800	4cm	2.73	0.33	6cm	2.50	0.32	0.02
2500	4cm	3.01	0.38	6cm	2.64	0.35	0.04
	4cm	3.01	0.38	7cm	2.67	0.37	0.04

Pleasantness. We found no effects of exploration time on pleasantness, $F(1, 12) = 2.11$, $p = 0.17$, $\eta p^2 = 0.15$, nor was there an effect of surface size on pleasantness, $F(4, 48) = 0.48$, $p = 0.75$, $\eta p^2 = 0.04$. However, we found an effect of grit size on pleasantness, $F(1.29, 15.53) = 19.41$, $p < .001$, $\eta p^2 = 0.62$, in which sandpaper surfaces with higher grit values (decreasing roughness) were rated as more pleasant than sandpaper surfaces with lower grit values. We also found an interaction between grit size and surface size, $F(24, 288) = 4.37$, $p < 0.001$, $\eta p^2 = 0.27$ (see Figure 3). There were no other significant interactions (time * grit size: $p = 0.21$; time * surface size: $p = 0.89$; time * grit size * surface size: $p = 0.30$).

The main effect of grit size and the interaction with surface size suggest that perceived pleasantness increases as a function of grit size. However, depending on surface size, the increase in pleasantness appears to follow different patterns. For small surface sizes, pleasantness increases relatively linearly with increasing grit size (i.e., decreasing roughness). Whereas, for large surface sizes, perceived pleasantness monotonically increases and reaches a plateau at a grit value of 2000. To explore this interaction effect further, we collapsed the data across surface sizes 1 and 2 (small = 4 & 5 cm) and surface sizes 4 and 5 (large = 7 & 8 cm) and analysed the combined data to get a better idea of the relationship between grit size and surface size, and their effects on perceived pleasantness.

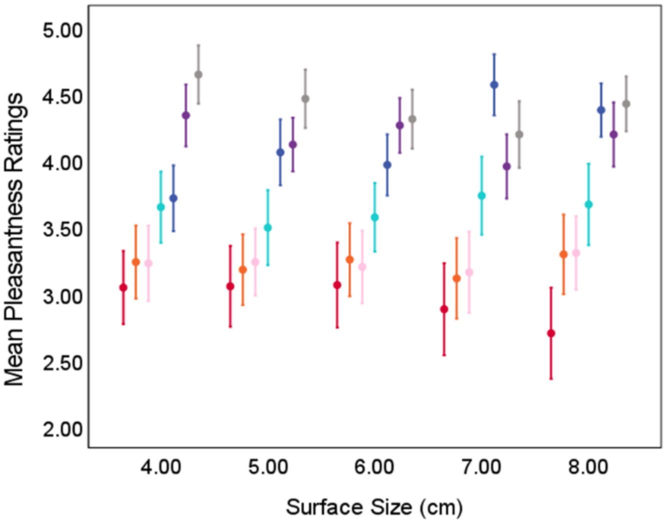

Fig. 3. Mean perceived pleasantness as a function of surface size. Error bars represent 1±SE. Each colour corresponds to a grit size: red = 600; orange =800; pink =1000; teal =1200; navy =2000; purple =2500; grey = 3000.

We conducted a repeated-measures ANOVA, with surface size (large and small) and grit size (600/800/1000/1200/2000/2500/3000) as the within-subjects variables and the pleasantness ratings as the dependent variable. As expected, we replicated the main effect of grit size on pleasantness ratings, $F(6, 72) = 18.69$, $p < 0.001$, $\eta p^2 = 0.61$, as well as the interaction between grit and surface size, $F(6, 72) = 8.40$, $p < 0.001$,$\eta p^2 = 0.41$, to clarify how the relations between grit size and pleasantness is influenced by surface size, we further computed Bonferroni-corrected differences between the two surface size conditions in linear and quadratic trends. This procedure fits previous observations showing that both material qualities and pleasantness can be described as a function of the logarithms of the underlying physical parameter based on linear and sometimes quadratic dependencies (roughness:[16], softness:[26]). These tests revealed a significant difference between surface sizes in the quadratic component in the function of perceived pleasantness on grit size, $F(1, 12) = 15.48$, $p = 0.002$, $\eta p^2 = 0.56$.

To better describe the difference, we fitted a polynomial function of 2nd order to the log pleasantness ratings separately for small and large surfaces. The R^2 values for the fitted polynomial function with log grit size were approximately 0.88 for the large surface and 0.97 for the small surface (see Figure 4). Overall, the effects of grit size on perceived pleasantness were similar for both surface sizes. However, the way in which perceived pleasantness increased relative to grit size varied depending on surface sizes. For smaller surfaces, the perceived pleasantness increased more steeply as grit size increased; in comparison, for large surfaces, the perceived pleasantness

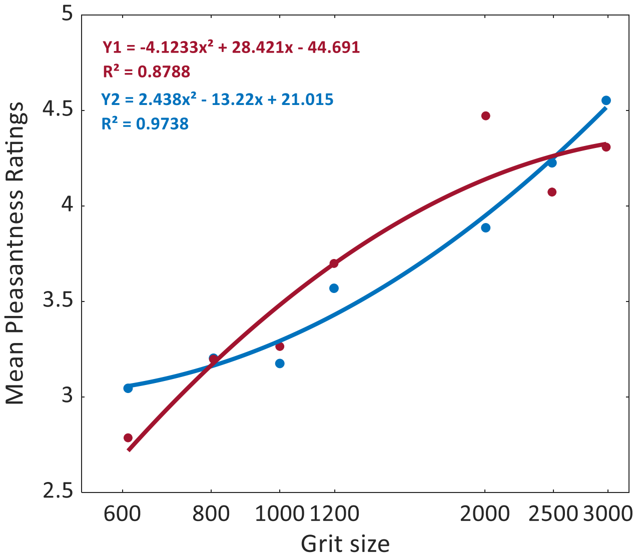

Fig. 4. Mean pleasantness ratings plotted as a function of log grit size for small (4&5cm) and large (7& 8 cm) surfaces. The x in the regression equations were based on log grit size. The X-axis was labelled with actual grit size values with log spacing ticks. The red line depicts pleasantness ratings for large surfaces, while the blue line represents pleasantness ratings for small surfaces.

decreased more steeply as grit size decreased, but the increase in pleasantness was less pronounced as grit size increased.

IV. DISCUSSION

Previous research has shown a connection between roughness and unpleasantness, with many factors influencing this relationship. This study examined how temporal and spatial presentation factors, specifically surface size and exploration time, influence the relationship between roughness and affective responses on pleasantness and arousal dimensions. It should be noted that perceived roughness was not directly measured in this study, as the relation between different grit sizes and roughness has been well-established in previous studies involving sandpaper stimuli.

We confirmed the effects of roughness – as associated with grit size – on perceived pleasantness and showed that roughness does not systematically covary with arousal. Further, we found that exploration time had little effect on perceived pleasantness and arousal. However, we observed interactions between grit size and surface, in which the influence of grit size on perceived pleasantness was modulated by surface size. Interaction effects on arousal were small and did not covary with those on pleasantness. Overall, our results confirm the view that arousal reactions are distinct from pleasantness and suggest that global features influence not only perceived roughness but also the perceived pleasantness of rough stimuli.

Our results are consistent with previous studies indicating that smoother surfaces (higher grit sizes) are perceived as more pleasant than rougher surfaces [3-5]. The textures used in this study fell within the range of fine roughness(7-25.8μm). Prior research on fine roughness perception has highlighted the involvement of Pacinian afferents in detecting vibrational information during sliding motion and contact with material surfaces [27-29]. Our study demonstrated that participants could discern between fine textures, and fine roughness could affect pleasantness perception. Although all mechanoreceptive afferents will likely be activated during tactile exploration, our findings suggest that the tactile pleasantness can be experienced throughout the body, including fingertips. Hence, we speculate that Pacinian afferents may play a role in pleasantness perception, particularly in glabrous skin areas where CT afferents are absent. Pacinian afferents may potentially take over some of the functions of CT afferents in detecting and transmitting information related to pleasantness perception [e.g. 7]. Nevertheless, this is purely speculative and further research is needed to explore the contribution of different cutaneous receptors to pleasantness perception, specifically in relation to fine roughness.

Our findings indicate that the exploration durations (2 or 3 seconds) did not significantly impact participants' pleasantness ratings of rough stimuli. It has been shown that roughness perception involves various aspects of texture properties beyond the physical definition of roughness, such as friction and spatial frequencies [30-32]. Some aspects of the texture properties related to physical roughness may be quickly detected upon contact with the material surface. Additionally, the task of rating pleasantness may have drawn attention to any potential unpleasantness. However, it’s important to note that our study only examined two specific exploration durations; therefore, it would be premature to rule out the presence of exploration time effects on perceived pleasantness. Possibly, shorter or longer exploration durations may result in different patterns of results and would bring insights into the underlying perceptual mechanisms. Alternatively, instead of exploration duration, restricting the spatial extent of exploration (i.e., number of exploratory movements from border to border) could also provide valuable insights into how such constraints influence pleasantness perception. Regardless, this question would be very interesting to explore in the future.

Mainly, we found a modulatory effect of surface size on the perception of pleasantness in relation to grit size. This effect is similar to what was reported in a previous study [15], which demonstrated an interaction effect between global features and local features on roughness perception. The study found that for coarse surfaces, global features had a substantial impact on roughness perception. However, as the surface roughness became finer, the influence of global features on perceived roughness diminished, leading to the conclusion that global features have little effect on roughness perception on their own. Instead, the interaction between global and local features affected roughness perception, with local features modulating the effect of global features. In light of these findings, we observed a significant interaction effect of grit size and surface size on pleasantness perception. Our results suggest that, similar to roughness perception, local features may have a greater influence on pleasantness perception, with global features likely only having a supplementary effect. However, it is worth noting that our study did not investigate perceived roughness, and therefore, further examination is necessary to fully understand the effects of surface size on both pleasantness and roughness perception.

In the present study, we did not explicitly instruct participants to explore the whole surface. Instead, participants were allowed to freely explore the material surfaces in any way they saw fit, as long as they were exploring using a single finger. Hence, the way in which participants explored the stimuli might have been influenced by the affective responses elicited by the material surfaces, particularly those that were unpleasant. Emotion theories have postulated the link between valence and action and that our affective responses to stimuli may serve as an evolutionary force that facilitates the adaptive selection of actions. For instance, a negative valenced stimulus may signal impending danger. The valence of stimuli we encounter has been shown to influence our behaviour [33-34]. Stimuli that evoke positive valence fosters approach behaviour (i.e., pursue), whilst stimuli that evoke negative valence trigger avoidance behaviours (i.e., withdrawal). Thus, depending on one’s initial affective appraisal of a given material, the resulting sensation may steer their behavioural orientation and influence how they explore the material.

Furthermore, besides roughness, abrasiveness was also a prominent property of the sandpaper used in our study. Even very fine abrasives can be intrinsically damaging to the skin and potentially impact the perceived pleasantness of the stimulus. Because both roughness and abrasiveness may be the sources of unpleasantness or discomfort, participants may have adapted their exploration strategy to avoid potential harm or discomfort from these properties of the surfaces. This adaptation may have led them to explore only parts of the surface to maximise their comfort and avoid potentially harmful stimuli. Especially when their task was not to discriminate but to rate the pleasantness of the surface explored, they had no incentive to prolong their discomfort and therefore had to obtain 'just enough' information to make their judgements. As a result, participants' ability to integrate surface size information may have been compromised or reduced, potentially explaining the lack of a strong effect of surface size on perceived pleasantness. To address this, we are currently running a follow-up experiment where participants are explicitly instructed to explore the entire surface of the stimuli, which may provide further insights into the influence of surface size on perceived pleasantness while controlling for potential adaptation strategies. Nevertheless, further studies are needed to fully elucidate the effect of surface size on perceived pleasantness, and one may also consider including interaction measurements, such as velocity and pressure, to gain a more comprehensive understanding of the factors that contribute to the observed effects.

Still, we observed an interaction effect between grit size (local feature) and surface size (global feature) on the perceived magnitude of pleasantness. We found that while the perceived pleasantness increased with grit size (i.e., increasing smoothness) for both surface sizes, there is a modulation effect of surface on the pattern in which pleasantness is influenced by grit size. Specifically, for smaller surfaces, the perceived pleasantness increased more steeply as grit size increased (i.e., increasing smoothness). Whereas for large surfaces, the perceived pleasantness decreased more steeply as grit size decreased (i.e. increasing roughness), but the increase in pleasantness was less pronounced as surface roughness decreased. Presumably, the less pronounced increase in pleasantness as surface roughness decreases might indicate that larger surfaces feel rougher and more unpleasant than smaller surfaces, even as the smoothness increases. Although we found that surface size had a modulatory effect on pleasantness perception, it remains unclear whether surface size also affects roughness perception in a similar way. Our experiment did not examine perceived roughness; hence, it is clear that further exploration of the impact of surface size on roughness perception is necessary to discern whether roughness and pleasantness stay correlated through the variation of this modulation factor.

Nonetheless, one potential interpretation of our results could be attributed to an imperfect integration of multiple object attributes at a higher-order processing level. Our perceptual systems have limited capacity and do not fully process all informational inputs. Information that is more salient or relevant to task goals is selected for priority/detailed processing, and salient attributes (e.g., prominence, intensity, affective valence) have been shown to substantially influence the final percept [35-36]. Information about different attributes of the stimuli is extracted in tandem and integrated by higher-order processes to form a single coherent percept. For instance, when grasping an object, we perceive it as a unified sensation rather than distinct percepts.

Research has shown that the human hand can process material properties more rapidly than geometrical ones, and haptic systems have been shown to initially weigh local features more heavily than global properties [37-38], which explains the stable influence of grit size (related to roughness) on perceived pleasantness in our study. However, large object size has also been shown to be a salient property that often immediately captures an observer's attention [39-40]. Therefore it is possible that while participants were focusing their attention on the surface texture and roughness as an object attribute was receiving priority processing from the perceptual systems due to its affective valence. Because of large objects' inherent saliency, more attention may be momentarily drawn to stimuli of large surface size, leading to a salience-driven overestimation akin to peak bias [41-42], which increases the overall perceived intensity of roughness and perceived unpleasantness of the stimulus as a whole. This explanation could explain the levelling out and the less pronounced increase in perceived pleasantness for large surfaces as roughness remains salient even when the stimuli roughness level decreases.

Alternatively, the present results may result from processing at a lower level (e.g., signal summation in local receptors). Based on our findings, we suspect that the contact area size between the material surface and skin could be relevant to the relation between perceived roughness and pleasantness. Despite the fact that participants did not necessarily explore the entire surface area, it is likely that larger surfaces led to greater skin-surface contact, including contact with the phalanges as well as the fingertip. This, in turn, could have resulted in more extensive skin-surface contact when exploring larger surfaces than when exploring smaller ones. Presumably, the more extensive skin-surface contact that occurred during the exploration of larger surfaces led to increased perceived roughness, which resulted in decreased perceived pleasantness. This conjecture resonates with previous findings that rough surfaces are perceived to be rougher when explored by two digits simultaneously compared to a single digit [4]. While this may be due to the summation of signals across multiple contact points during roughness perception, it could also be interpreted as the perceived roughness amplified by the increase in the contact area between the surface and the skin. Future research should investigate this further to determine the underlying mechanisms and contribute to a deeper understanding of the perceptual effects of contact area size on roughness perception and/or pleasantness perception.

The current study examined the influence of temporal and spatial presentation factors on the perception of rough stimuli in terms of pleasantness and arousal. Our findings suggest that exploration time had little influence on the affective responses in relation to roughness perception. However, we observed a modulatory effect of surface size on the perceived pleasantness of rough stimuli. This effect may be related to the influence of global features on roughness perception, as suggested by previous research. Our findings highlight several areas for future investigation, including the role of surface size in roughness perception and the contribution of different cutaneous receptors to pleasantness perception in the context of fine roughness. There remain many open threads to explore in order to gain a deeper understanding of the complex relationship between spatial and temporal presentation factors and the affective responses to rough stimuli.

Acknowledgment

The authors thank Hatice Bajrami and Viktoria Neuwirt for the data collection and Lale Can for helping with the stimuli preparation.

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