

Effects of Material Touch-Sounds on Perceived Quality of Surfaces

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ABSTRACT

The vehicle interior constitutes the multi-sensory environment of driver and passengers. Beside overall design and execution, materials and its surfaces are of specific interest to the customer. They are not only needed to fulfil technical functions, but are in direct focus of the customer's perception. The perceived quality is based on all sensory data collected by the human perceptual system. Surfaces express design intent and craftsmanship by their visual appearance. Haptic features supervene when materials are touched. And even smell has an influence on the perception of ambience. Although sound is generated nearly every time when fingers slide across a surface, touch-sounds have been disregarded so far. In various cases, these contact sounds are clearly audible. As essential sound responses to haptic activity, they can degrade perceived quality. A method has been developed for a standardized generation of touch-sounds. It includes simulation of a realistic finger force, touch area and sliding velocity. Sounds generated on numerous steering wheel materials have been recorded. The sounds were played back to participants under exclusive auditory conditions. The influence of psycho-physical parameters and iconic sound features on perceived quality has been investigated. Furthermore, the interaction of sound sensation with visual and haptic features was studied. Results demonstrate that the sound excited by fingers sliding across a surface contains essential information about the nature and the quality of materials applied. This enables the choice of materials with maximized multi-sensory harmony.

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INTRODUCTION

In common understanding, product design and styling are tasks which mainly focus on the visual appearance of useful objects. However, in parallel to the sense of vision, other senses (modalities) are continuously active in the waking state of a human being. Quite fundamentally there is an effort of each individual to perceive both natural and artificial objects not only with the eyes, but also by touching (tactile/haptic) as well as with the sense organs for sound, odor and taste. In addition, sensations of temperature, bodily balance, muscle tension and movement play an essential role, although they tend to appear only incidentally in the consciousness. The customer's perception and assessment of products is decisively influenced by subliminal processes. Even when an object is initially approached via just one sense, this evokes contributions from further modalities, fed from the stored memory of past perceptual experiences.

A variety of senses is simultaneously involved in the process of vehicle operation. Visual, auditory and tactile stimuli are indispensable enablers for safe operation of the technical system via the whole human machine interface (HMI). The movement of a car is perceived by the sense of balance (vestibular) and as changing conditions of body feel (interoception). During the use of operating elements, movement and tension of the limbs are controlled by means of proprioceptive stimulation. Activation sounds provide essential

feedback on the correctness and effectivity of operation. Even odor plays an important role in delivery of atmospheric feedback and emotional content of the interior environment.

Looking at interior materials, the visual appearance triggers expectations regarding the sensations to be expected from touching it. In addition to visual properties the multi-sensory appearance of a surface includes tactile perceptions, touch sounds and smell (olfactory) sensations [1]. To create a harmonized overall perception it is necessary to adjust the material properties registered via the different senses in such a way that an overall impression is obtained which is free of contradictions. The method of Synesthetic Design offers a comprehensive, systematic concept for the optimization of multi-sensory design work [2]. This includes optimum integration of auditory features into the multi-sensory environment. Three types of material related sound need to be distinguished:

- Squeak and rattle phenomena occur when two or more materials are rubbing against each other. This causes rubbing noise, impulses and/or stick-slip movement. Those sounds occur by means of inner material tensions, thermal expansion, vibration input or deflections induced by haptic activity of the driver.
- Sounds generated when people are intentionally knocking upon panels in order to test the quality of material and assembly.

- Sounds excited when fingers or hands slide across a surface. This is often coupled with the operation of elements like switches or steering wheel, or to haptic search on such elements.

This paper will exclusively focus on the last-mentioned case of surface touch-sounds. Various studies have proven that these sounds influence the tactile perception [3]. They thus show a high potential to subconsciously modify the perceived quality of interior surfaces. Touch-sounds can either contribute to authenticity and high quality of interior surfaces, or can destroy the impression that genuine and good materials are used [4]. Auditory contributions thus complete the number of senses which communicate appropriate use of materials to the customer.

Currently, it is not possible to predict the materials potential for excitation of touch sounds by measurable mechanical parameters. In cooperation with external institutes, a variety of test methods has been applied to test samples in order to establish a complete set of relevant parameters. Tested parameters are: adhesion tack value, surface friction, surface roughness, damping constant, free surface energy (contact angle of a fluid), stick-slip sensitivity (risk priority value RPZ) and shear resistance. Except material damping, the parameters showed weak or no correlation with the perception of touch sounds. Therefore the below-mentioned investigations had primarily to be based on perceptual experiments.

MULTI-SENSORY PERCEPTION OF PRODUCT FEATURES

During daily life, nearly every human activity is facilitated by feedback provided via different senses. Furthermore, carrying out the vast majority of activities would not be possible without multi-sensory interaction. In the case of the ballpoint pen, writing noise supplies important information about the hardness of the writing surface. It should neither be too soft (quiet sound) nor too smooth (no sound or a different sound quality) nor too rough (intermittent sounds). The correct functioning of the pen is thus communicated not only by the tactile sensation experienced when the point of the pen is applied to the paper but also by the noise the ball makes as it rolls over it.

The information coming in from one sense has an influence on the perceptual data coming in from the others. It has been shown by various investigations that the visual image of a car modifies the perception of the vehicle sound (e.g. [5]). In a similar manner, the haptic appearance of a surface is influenced by the sound generated during touch: When fingers slide across a surface, it is perceived as even rougher when a harsh noise is generated simultaneously. Furthermore, unevenness in the surface will usually be seen more clearly when it is possible to feel it at the same time. In view of these cross-sensory interactions, the analysis of touch-sounds is dealing with the quality of materials as conveyed by sound rather than with the quality of sound itself.

Investigations of the perceived quality of materials have to include all senses involved. The task of multi-sensory optimization is typical for development of complex products like the automobile. Usually, visual, tactile, auditory and olfactory contributions need to be assessed. In the automotive industry, these tasks are split and addressed by various experts, performing a separate optimization of product features which approach the various senses. The multi-sensory appearance of the product, however, can only be optimized if interactions between the senses are taken into account. This finally leads to a state of cross-sensory harmonization which fits expectations of today's customers.

The perceptual system generally tends to produce a non-contradictory model of objective reality. Thus, matching of data provided by the sense organs is more intuitive in case the sensations are well correlated. A taxonomy of principle strategies of multi-sensory integration, as applied by the perceptual system, has been discussed before [2, 6]. Cross-sensory correspondances (analogies), iconic connections (associations) and merging of symbolic content are of crucial importance to product design. These enable the intuitive connection of sensory data between the modalities. As an example, a touch-sound may show a specific roughness which correlates to the perceived visual grain and the haptic roughness of the surface via cross-sensory analogies. Furthermore, perceived features like roughness show an associative potential, which points to former perceptual experience: "It sounds rough like touching cork" or "it sounds smooth like vinyl". These iconic connections thus support identification of a material by means of characteristic elements of its touch-sound.

TOUCH-SOUND AND MATERIAL QUALITY

In the past, the definition of surfaces for the vehicle interior was mainly seen as a task of visual design and engineering of haptic qualities. But hearing is involved as well: Auditory-tactile interaction is an essential part of switch feedback, e.g. when pushing a button. Sounds generated when a surface is being touched significantly influence quality feel and identification of the material.

During the last decades, noise emissions of major sound sources of the vehicle have been significantly reduced. As an example, vehicles equipped with an electric drive present much less powertrain noise than those using a combustion engine. As a result, driving is much more comfortable. At the same time, however, sources of soft sounds are more audible. Thus, also touch-sounds gain increasing importance. The sound generated when a vehicle U-turn is done and the driver lets the steering wheel slide through the hands (with loose contact between fingers and surface) is clearly audible and can be amongst the loudest sounds perceived inside the car (Fig. 1). Touch-sound supports the identification of the material being touched. Moreover, in many cases an unambiguous identification is enabled just via the auditory sensation.

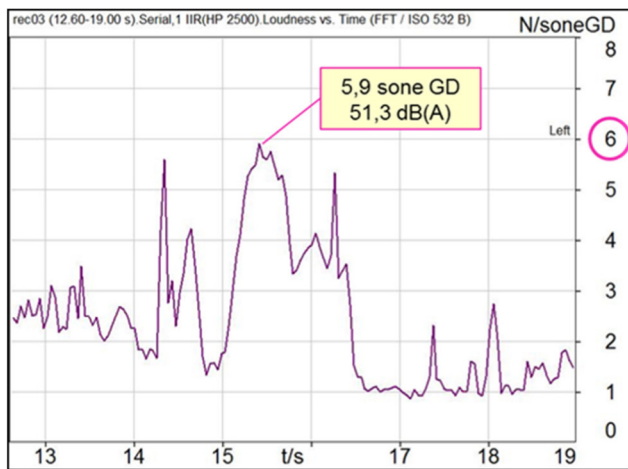


Figure 1. Measurement result of touch-sound of a steering wheel during driving of a U-turn. Engine sound has been removed by HP-filtering at 2.5kHz.

Identification of materials is thus also based on the iconic features of sound, which refer to the other senses. The iconic features of touch-sounds were described as *materializing sound indices* by Chion [7]. These parameters need careful analysis for optimization of the multi-sensory appearance of materials. It is evident that sounds generated by touching paper, hard plastic, metal, leather, fabric or felt transmit quite different impressions of the materials' natures and qualities. Beside applications for product design, knowledge of material representation by sound is essential for communication of material properties in movies and all kinds of virtual environments [8].

Touch-sound is excited at the interface between finger and interior part as shown in Fig. 2. A normal force is applied to the surface. It causes material deflection and a partial alignment of the surface and the skin of the fingertip. When the finger is moved across the surface, friction occurs according to the normal force applied. This usually causes a broad-band noise in the mid- and high-frequency range, e.g. between 1,000 - 20,000Hz.

Additional effects can occur due to dynamic change of friction:

- high-frequency tonal squeal
- stick-slip with its characteristic low frequency fluctuation and roughness, caused by periodic changes from static to dynamic friction
- tonal rubbing noise caused by a periodic element of texture

The acoustic energy is radiated as air-borne sound from the gap which surrounds the fingertip. Additionally, structure-borne sound is transmitted into the structure. It partly propagates through the material to other areas of the surface, from where it is radiated as air-borne sound, too. On its way to the surface areas of radiation, inner material damping becomes effective. Another portion of excited acoustic energy, however, is transmitted to the substructure. It thus can affect neighboring parts, which may be more critical for noise radiation. Furthermore, secondary noise can be excited when the substructure hits or rubs towards neighboring parts, thus causing squeak & rattle (S&R).

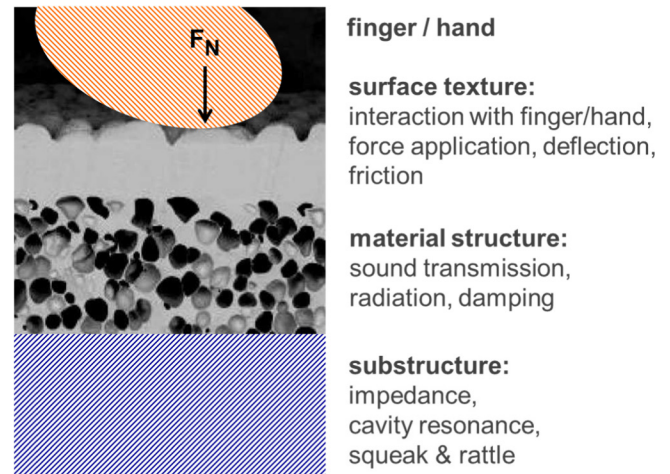


Figure 2. Interface between finger/hand and interior part.

The relation of the acoustic impedances of the upper layer and the substructure, respectively, defines the amount of energy transferred. Below the substructure, cavity resonances can amplify specific frequencies of sound and thus increase loudness and annoyance of sound.

Touch-Sound Test Set-Up

For evaluation of surface parameters which significantly influence the touch-sound, a method for reproducible excitation is needed. Its aim is to enable a standardized recording of touch-sound. As a first approach, a method was developed for investigation of flat material samples (size A4), as delivered by material suppliers. The excited touch-sound is correlated with the friction induced. For that reason, the normal force of the finger applied to the surface is an important parameter, which needs to be controlled. A rigid mass has been chosen for application of a constant normal force [9]. This "artificial finger" is pulled across the material at constant speed. A standard measurement device (SQuadriga by HEADacoustics/Herzogenrath, Germany) was used for sound recording. In the next step, the recorded sounds from various materials can be modified, e.g. filtered or normalized. A set of sounds is then presented to a group of participants for subjective assessment. The touch-sounds are thus decoupled from the other senses and from individual variations of the haptic conditions.

The first intention was to use a mechanized system which pulls the artificial finger by means of an electric drive. This requires a drive with very low sound emissions and a control of particular accuracy. In view of these complications, it was decided to start with a simple procedure, which includes pulling of the artificial finger by hand (Fig. 3).

The artificial finger consists of steel. It allows the optional attachment of an accelerometer. The configuration needs to avoid stick-slip effects and disturbing resonances. The weight of the artificial finger simulates a standard normal pressure applied by the fingertip. During human haptic activity, this pressure is a result of an active biodynamical adjustment of the friction. Here, it is simplified as a constant "virtual weight" of the human index finger.