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Probing With and Into Fingerprints

Ravinder S. Dahiya and Monica Gori

Robotics, Brain and Cognitive Science Department, Italian Institute of Technology, Genoa, Italy

Dahiya RS, Gori M. A recent report by Scheibert et al. highlights the role of fingerprints in enhancing tactile sensitivity. By scanning a surface with a biometric force sensor they demonstrate the dominance of the frequencies that fall within the optimal sensitivity range of Pacinian afferents. The sensor, in this study, has a soft cover patterned with parallel ridges—mimicking the fingerprints. However, the skin structure is quite complex. Elasticity of the skin varies with depth and the ridge like pattern is comprised of not just papillary ridges or fingerprints. Besides fingerprints there exist intermediate ridges, positioned exactly under the papillary ridges, and limiting ridges at dermis-epidermis junction. These structures are usually considered as single unit. If so, it is important to revisit and see if the role of fingerprints remains the same, should the sensor cover have both fingerprints and intermediate ridges.

Many in the neuroscience and robotics community are fascinated by recent report on fingerprints or papillary ridges facilitating perception of fine textured surfaces (empirically defined as those with predominant spatial periods of $\lesssim$200 μm) (Scheibert et al. 2009). From this finding it emerges that fingerprints not only help nab a criminal or improve our grip on slippery objects, they may also enhance our capability to detect fine textured surfaces, such as a cotton sleeve or a wooden table.

According to state of the art, the texture perception in humans is believed to be mediated by two mechanisms (duplex theory): a spatial code that works for coarse and medium surfaces (spatial scale $\gtrsim$200 μm) and a vibrotactile code that works for fine surfaces (Hollins and Bensmaïa 2007). A number of psychophysical studies, taken as a whole, support this view on two coding mechanisms mediating the perception of fine and rough surfaces, with each code operating effectively over a range of texture scales where other code is weak. Few studies have also pointed, albeit in a modest way, toward spatial and vibrotactile codes operating together in the texture perception of a surface (Gescheider et al. 2005; Yoshioka et al. 2001). However, a number of arguments (Hollins and Bensmaïa 2007) that support the existence of simultaneous operation of the two codes, as well as those opposing it, fail to provide a compelling case and clearly more research is needed to validate this hypothesis. The physiological mechanisms and the receptors involved in perception of textures, too, need to be individuated. The latter point has been addressed by a number of studies, following which it is known that the perception of coarse surfaces, engaging spatial code, is mediated by slowly adapting type-I (SA-I) afferents (Johnson et al. 2002). In fact, spatial variations in SA-I firing rates have been observed to account for fine surfaces down to 100 μm, thus invoking the principle of parsimony, that only one code underlies the texture perception (Yoshioka et al. 2001). The studies on perception of fine surfaces via vibratory code largely point toward the role of Pacinian corpuscles (PCs) (Bensmaïa and Hollins 2005). However, unlike SA-I, our knowledge of PCs mediating fine texture perception is based on indirect studies that do not use actual neural recordings and thus the extent of involvement of PCs is still being debated.

Adding to the scenario about the role of PCs in fine texture perception via vibrotactile code, Scheibert et al. (2009) provide circumstantial evidence on how the fingerprints or papillary ridges, present in human glabrous skin, could augment tactile inputs to the PCs. In their study, Scheibert et al. (2009) use a force sensor with a skin-like elastic cover, patterned with parallel ridges mimicking the fingerprints. While scanning this force sensor arrangement with a white noise one-dimensional textured surface, the vibration spectrum is found to be dominated by a frequency that is set by the ratio of scanning speed to the distance between two ridges—thus suggesting that fingerprints or papillary ridge–like structures allow for conditioning of the texture induced vibrations and perform spectral selection. Scheibert et al. (2009) verified this mechanism over limited scanning velocities ($\leq$0.4 mm/s) that are actually much lower than those experienced during typical exploratory tasks. Still, if scan velocity values in the range of 10–15 cm/s, experienced in a typical exploratory task, and the interridge distance value of about 500 μm (typical distance between papillae of human skin) are used in the method proposed by Scheibert et al. (2009), then dominant frequencies are found to be in the range 200–300 Hz. This frequency range falls within the maximal sensitivity range of PCs, thus leading Scheibert et al. (2009) to propose that fingerprints could augment inputs to the PCs. In view of these new revelations, there is also a need to revisit the previous results obtained by finite element modeling of the human skin, which report that fingerprints do not affect the response of PCs (Maeno et al. 1998). Another intriguing outcome of the method proposed by Scheibert and colleagues (2009) is the Gabor filter–like spatial term in the response function. The outcome, however, is not in agreement with previous studies, which suggest that PC afferents do not provide any spatial information to the CNS. The work of Scheibert et al. (2009) deepens our knowledge about the elaboration of tactile information in human glabrous skin. At the same time, the study also opens avenues for investigating various other aspects of fingerprint-led augmentation of tactile inputs such as the changes that occur when a wider range of scanning velocities is actually used or when the spatial information processing is mediated by PCs. Perhaps using an array of fingerprinted force sensors over a wider range of scanning velocities can be useful in further investigations.

The study of Scheibert and colleagues (2009) also adds to our knowledge about the role of skin structure. In their study, they patterned an elastic material with fingerprint-like structures to obtain a simplified version of glabrous skin. However, our skin structure is quite complex, having different kind of

Address for reprint requests and other correspondence: R. S. Dahiya, Robotics, Brain and Cognitive Science Department, Italian Institute of Technology, Via Morego, 30, Genoa, 16163, Italy (E-mail: ravinder.dahiya@iit.it).

receptors embedded at various depth levels and transducing signals with specific spatiotemporal characteristics. The elasticity of skin varies with depth. Further, fingerprints are not the only microstructures in the skin. There are also the intermediate ridges positioned exactly under the papillary ridges and the limiting ridges at the dermis–epidermis junction (see Fig. 1). Fingerprints are established during the 10th to 16th wk of pregnancy, after intermediate/primary ridges are formed at the epidermis–dermis junction due to stress-governed buckling instability (Kücken and Newell 2005). Interestingly, the intermediate ridges house the Merkel cell complex—the physiological transducers of SA-I receptors (Guinard et al. 1998) that are important for elaboration of spatial stimuli related to the form and texture and respond when the skin surface is deformed (Johnson 2001). The fingerprints and intermediate ridges have such a strong anatomical connection that they have been considered to be a single unit with the intermediate ridge, acting as a lever magnifying the indentation imposed at the papillary ridge (as suggested by Cauna's lever arm model; Cauna 1954). Since Merkel cells lie at the tips of the intermediate ridge it is suggested that papillary ridges directly influence how SA-I receptors respond to indentation at the skin surface (Cauna 1954). Arguing the validity of Cauna's lever arm model, Gerling and Geb (2008) demonstrate, with finite element modeling, that even though correctly representing the anatomy the function of intermediate ridges is distinct from that of papillary ridges. If so, both papillary ridges and intermediate ridges may affect the response of various receptors in the skin to different degrees. In fact, contrary to the belief that papillary ridges influence the response of SA-I receptors (Cauna 1954) by taking advantage of the presence of Merkel cell complex at intermediate ridges, Gerling and Geb (2008) demonstrated that they may not directly affect the response of SA-I receptors.

If fingerprints and intermediate ridges are considered to be a single unit, it is imperative to investigate and assign the role of intermediate ridges. Yet, Scheibert et al. (2009) considered only the effect of fingerprints but not that of other microstructures present in the skin. However, the role of intermediate ridges for enhancing tactile sensitivity of PCs or any other mechanoreceptor needs to be investigated. They might be enhancing the tactile sensitivity in the same frequency range of fingerprints or they may be effective in different frequency ranges. It would be interesting to see whether the role of fingerprints remains the same as demonstrated by Scheibert et al. (2009), should the biomimetic sensor be covered with a structure that has both fingerprints and intermediate ridges (see Fig. 1*C*).

The study of Scheibert et al. (2009) adds to our knowledge about the role of skin morphology in enhancing tactile sensitivity and tactile data processing mediated by PCs. It opens avenues for using fingerprint-like structures to improve tactile information gathering and thus utilization in other areas such as robotics, prosthetics, and haptics. The touch sensors used in such applications are usually covered with soft and elastic covering to improve robustness. In many robotic applications, the use of elastic covers with fingerprint-like structures, to improve grip and to prevent slip, for instance, have been reported previously. However, in the absence of any analysis such as that presented by Scheibert et al. (2009), the elastic covers (fingerprinted or not) on touch sensors in robotic applications have been thought to act as low-pass mechanical filters whose cutoff frequency depends on material properties of the elastic cover. Thus the elastic covers have generally been known to suppress the high-frequency component of tactile information and thus desensitize the touch sensors (Maeno et al. 1998). Thus from the perspective of robotic applications the analysis reported by Scheibert et al. (2009) is useful because

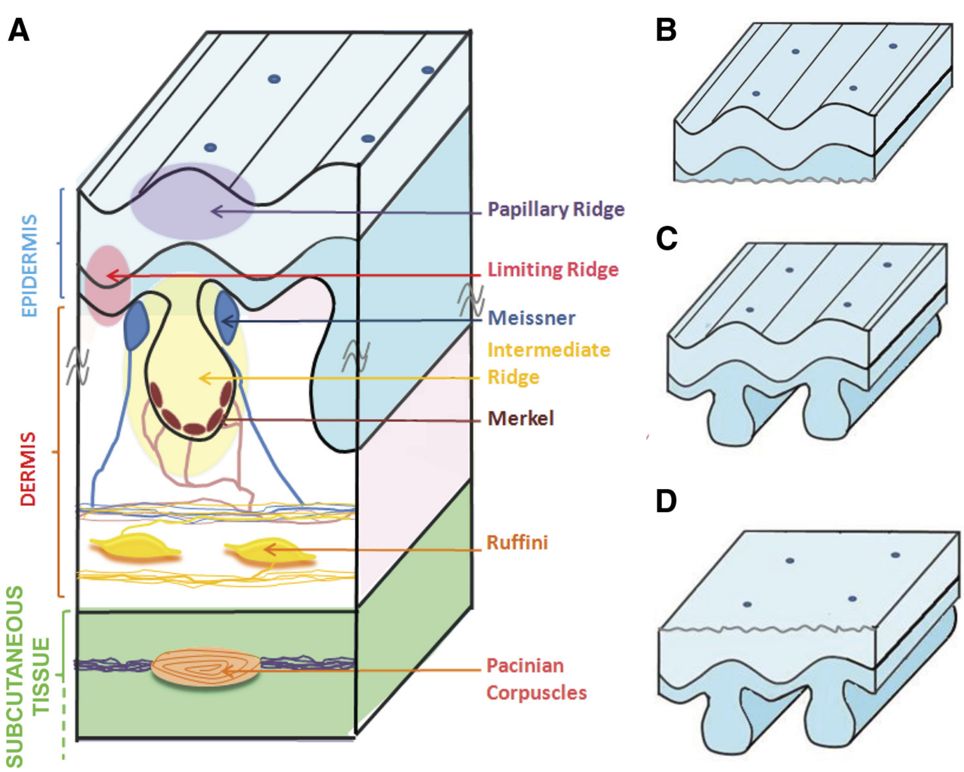

FIG. 1. *A*: skin structure showing various microstructures. [It should be noted that recent studies point toward the presence of Ruffini afferents in the hairy skin of human hand and not in the glabrous skin (Mountcastle 2005; Paré et al. 2003).] *B*: soft cover with fingerprints. *C*: soft cover with both intermediate ridges and fingerprints. *D*: soft cover with intermediate ridges only.

algorithms based on such analysis can be used to broaden the scope of touch sensors that are already in use.

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