Information about present and past stimulus features in human tactile afferents

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Background

The tactile system of the human fingertips provides quickly and reliably crucial information for control of dexterous object manipulation. Decoding of relevant sensory information involved identifying features like curvature of contacted objects and directions of fingertip forces. A complicating factor is that not only the current but also previous fingertip stimuli may influence the afferent signals because of viscoelastic properties of the fingertips. We based the analysis on neural responses in single afferents (43–72 FA-I and 49–73 SA-I afferents) recorded by microneurography when the human fingertip was repeatedly stimulated with spherical objects of three different curvatures, each applied in five different force directions (Figure 1).

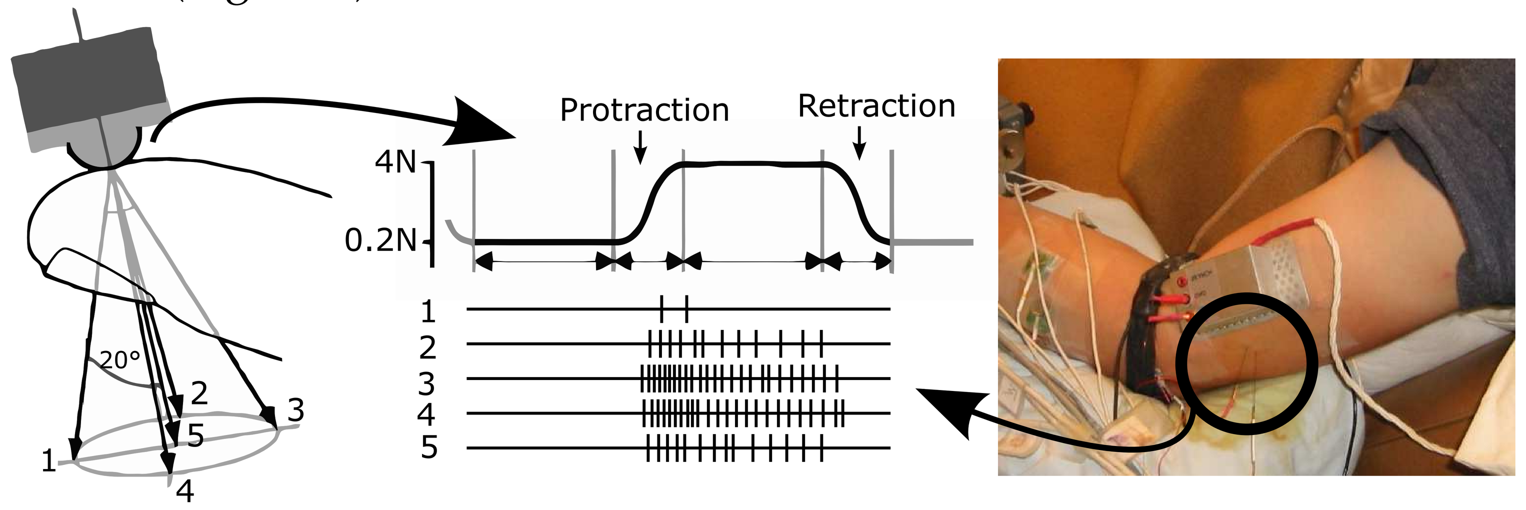

Figure 1: Microneurography: Tungsten electrodes were used to record impulses in single tactile afferent neurons while stimuli of three different curvatures were applied to the fingertip in five different force directions.

Information contained in spike times

An analysis of spike trains from individual afferents revealed that information about the stimulus is at least 60% (force direction) to 190% higher when spike timing is taken into account as compared to when only spike counts are used. Moreover, the first spike latencies carry a considerable amount (about force direction) or even more information (about curvature) than there is in spike counts (Figure 2). We found that information about different tactile features is spatially distributed over the fingertip, with afferents ending close to the stimulation site carrying high information about curvature and afferents ending farther away being most informative about force direction. (Figure 3).

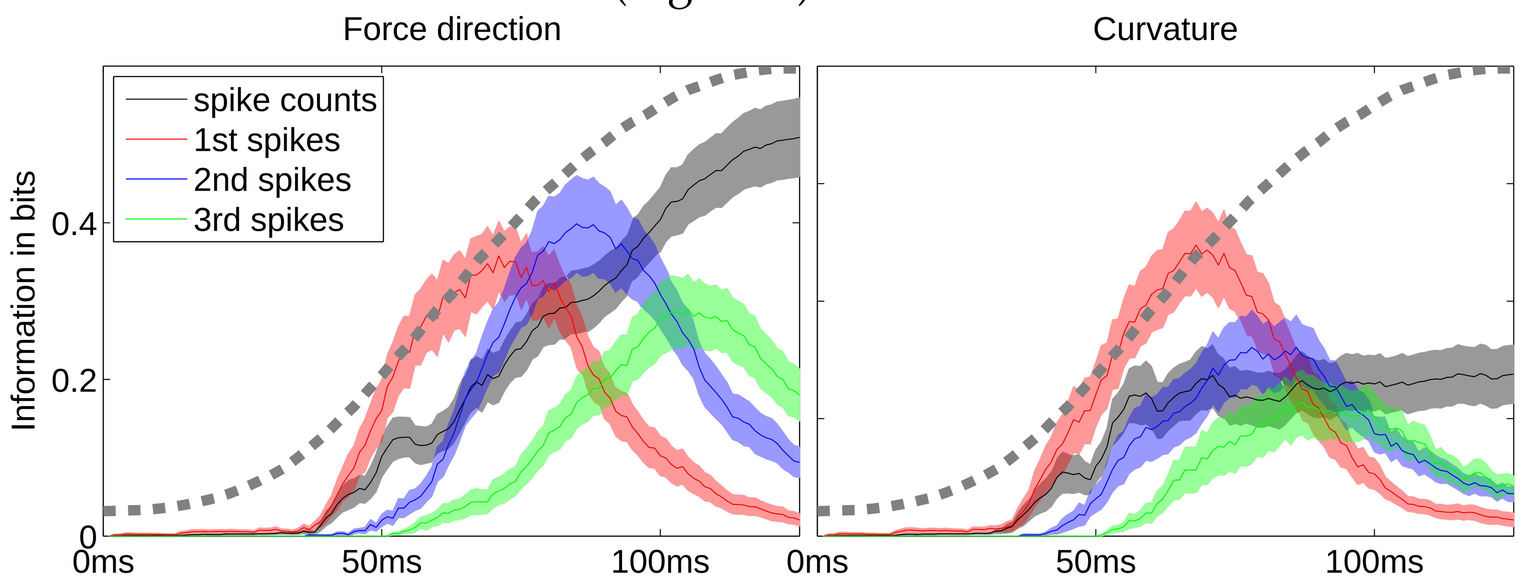

Figure 2: Average mutual information transmitted by the first spikes (red), second (blue), and third spikes (green) independently over time with a sliding window of size 30ms. Black lines correspond to the average information contained in spike counts. **Left:** Force direction. **Right:** Curvature.

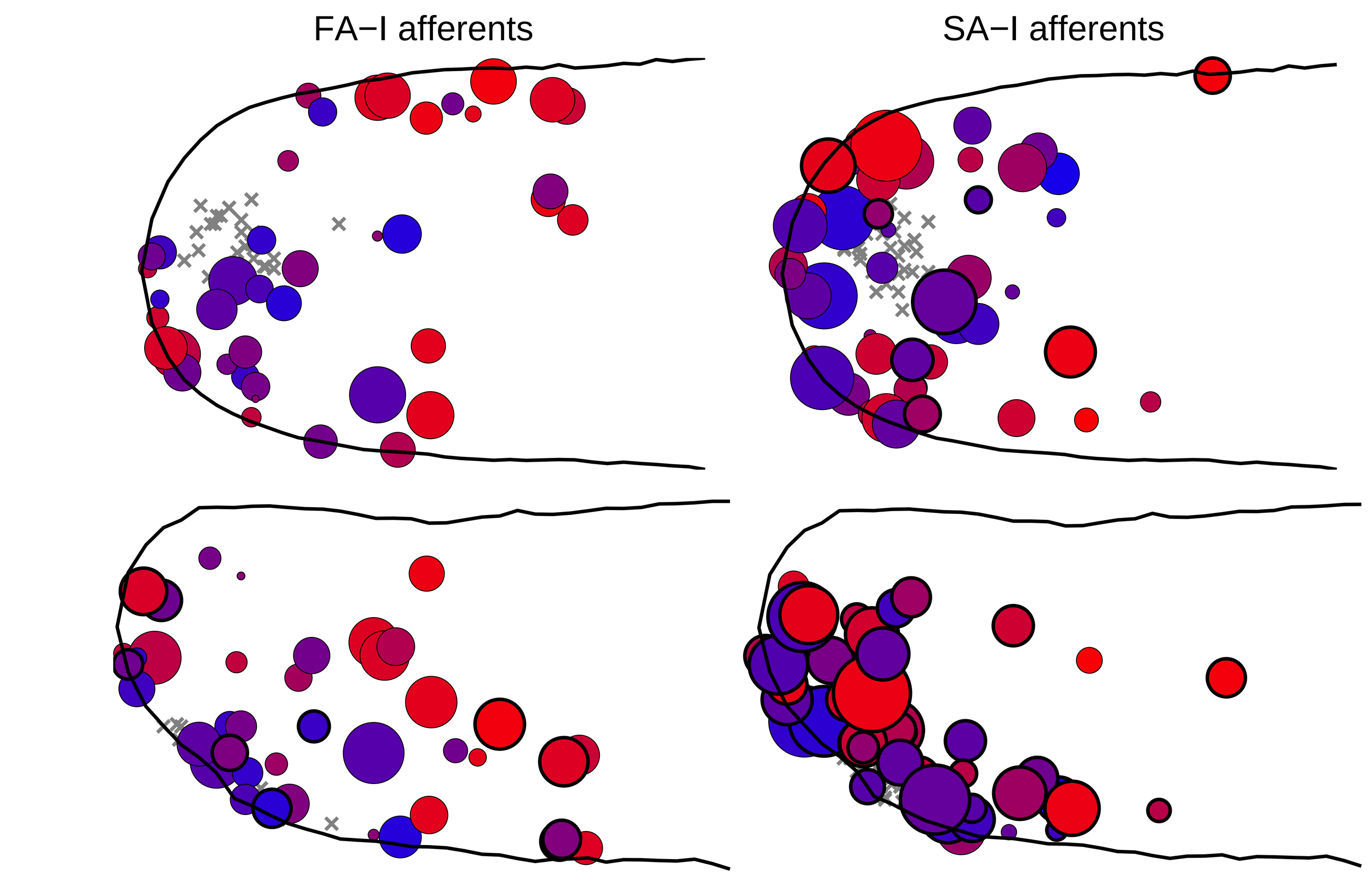

Figure 3: Information about curvature (blue) and force direction (red) per afferent as projected onto the fingertip. Top row: View from above. Bottom row: View from the side.

History effects

Previous fingertip stimulation influenced systematically the latencies of the afferents' first spikes, presumably due to viscoelastic properties of the fingertip (see Figure 6). This effect complicates fast and correct classification of the current stimulus. We found that first spike latencies contain information enough to classify reliably and quickly the nature of the preceding stimulus (Figure 4, left). Furthermore, knowledge about the previous stimulus enhanced classification of the current stimulus (Figure 4, right). That is, classification improved after reducing the jitter in the first spike latencies by compensating for estimated latency shifts caused by the past stimulus (Figure 5).

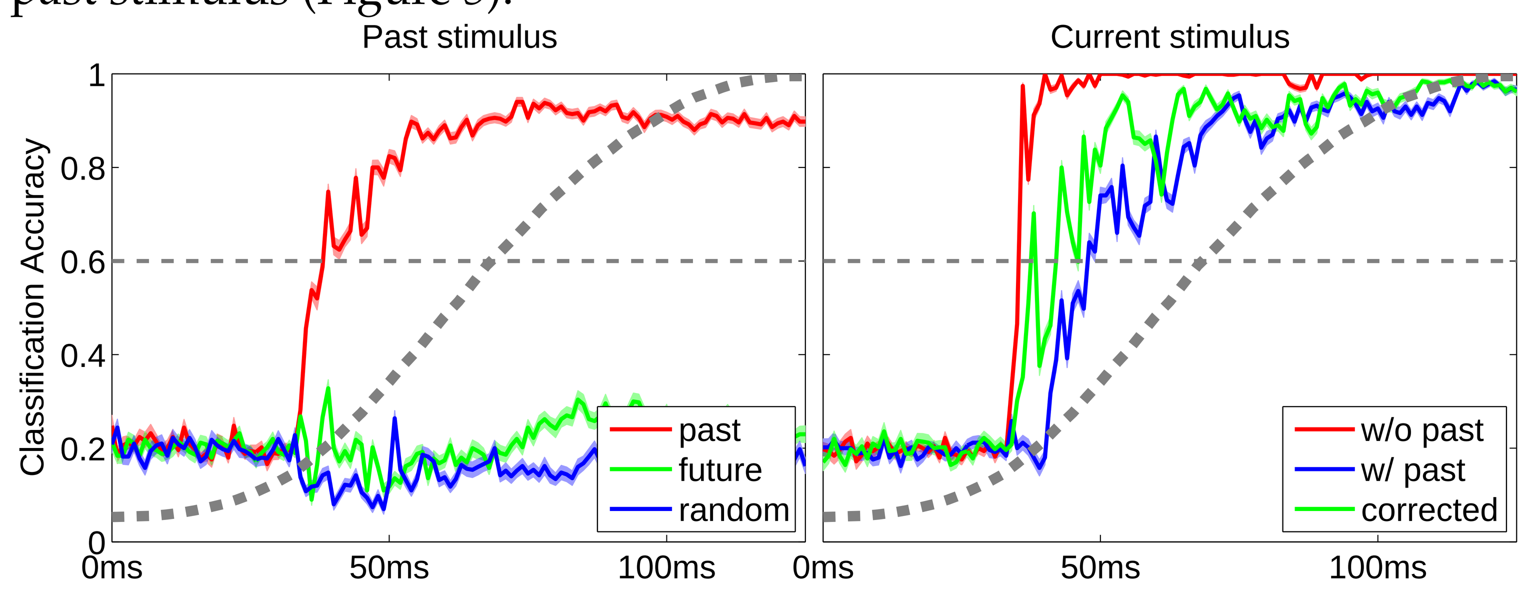

Figure 4: Left: Classification accuracy over time when discriminating the force direction of the preceding stimulus based on the first spikes as recorded for the current stimulus (red). Blue and green lines denote control conditions. **Right:** Classification accuracies over time when discriminating the currently applied stimulus without previous influence (red line), when a random stimulus was earlier (blue), and when the first spike latencies were corrected for the influence of the earlier stimulus.

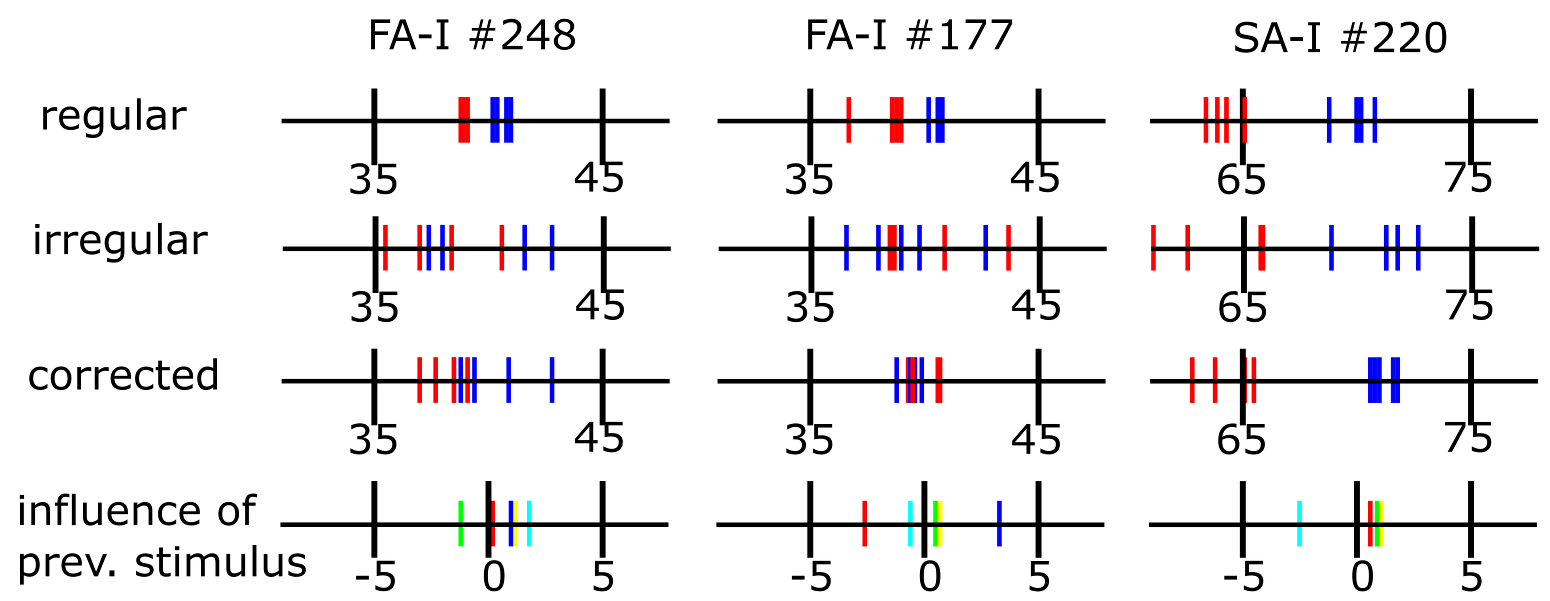

Figure 5: First spikes latencies of two tactile afferents for two different stimuli. **First row:** Without influence of past stimuli. **Second row:** When preceding stimulus is varied randomly. The jitter is around three times higher. **Third row:** Same latencies corrected for the influence of the preceding stimulus. The jitter has been reduced by around 30 percent. **Bottom row:** Estimates of first spike latency shifts due to preceding stimuli.

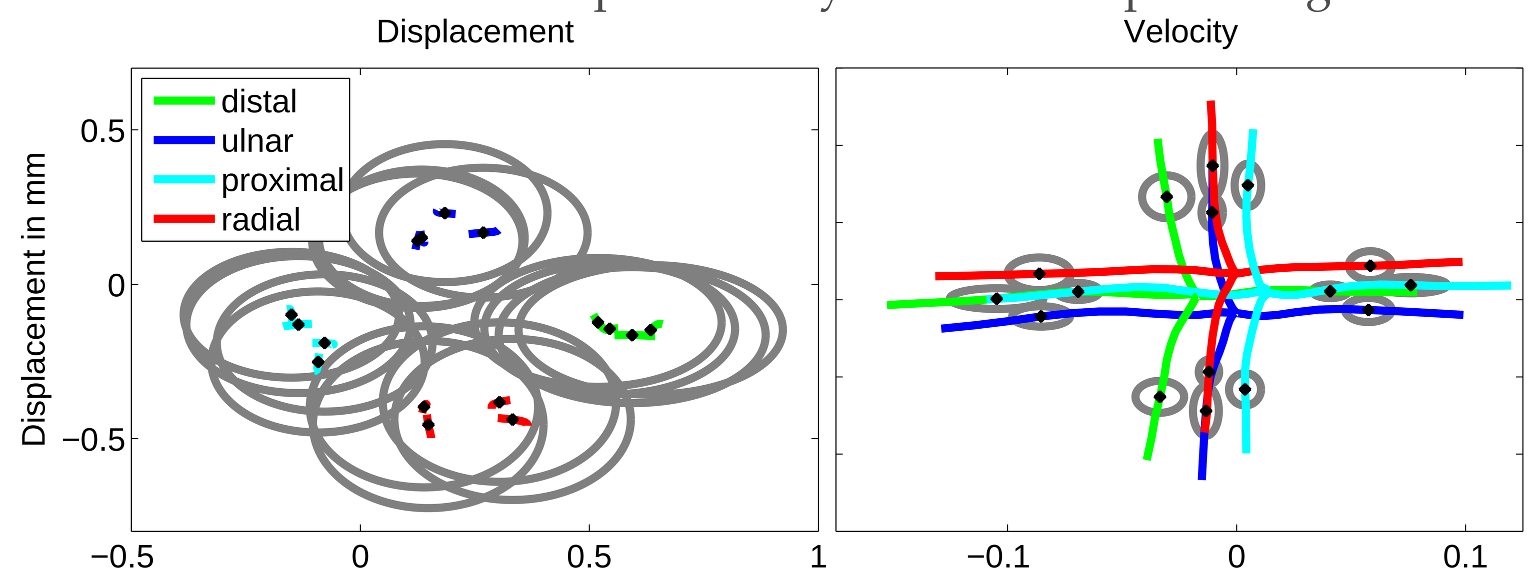

Figure 6: Lateral skin position over time between stimulus onset and 40ms after. Black marks denote 30ms point, with gray circles giving standard deviations at that time. Lines of equal color correspond to the same *previous* force direction.**Left:** Absolute displacement in mm. **Right:** Displacement velocity in mm/ms.

Conclusions

- Relative timing of spikes in ensembles of tactile afferents transmits high information about fingertip parameters.
- The timing of especially the first spikes contains rich information and sometimes even more information than there is in firing rates.
- In addition to these temporal properties, the human tactile afferent population exhibits distinct spatial properties, regarding which afferents respond to which features.
- Stimulus history influences first spike latencies in a regular way and knowledge (e.g. memory) about the past stimulus received improves classification of the current stimulus.

References

[1] Johansson RS & Birznieks I, Nature Neuroscience 7(2): 170–177, 2004.

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