Spatiotemporal distribution of tactile information across the human fingertip

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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 involves 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).

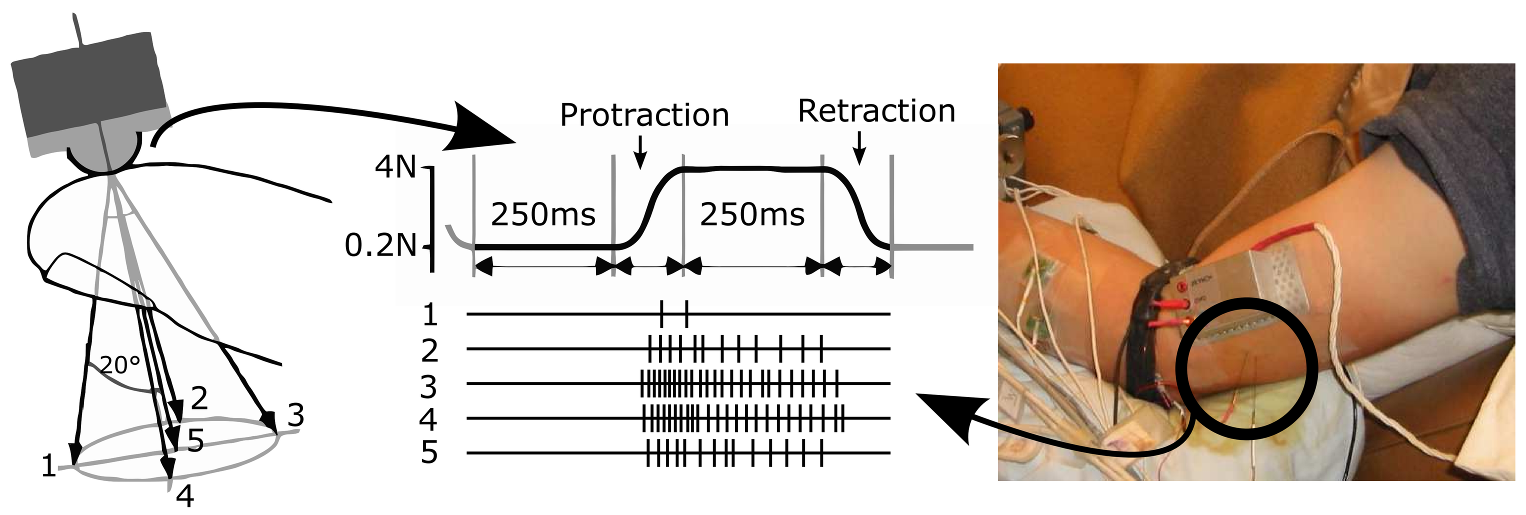

Figure 1: Microneurography: Tungsten electrodes were used to record impulses in single tactile afferent neurons while stimuli of three different curvatures were applied to the fingertip in five different force directions.

Information contained in spike times

An information-theoretic analysis [1,2] of spike trains from individual afferents revealed that information about the stimulus is at least 60% (force direction) to 190% (curvature) higher when spike timing is taken into account as compared to when only spike counts are used (Figure 2). The temporal resolution at which the highest amount of information is present falls between 8 and 16 ms for most afferents.

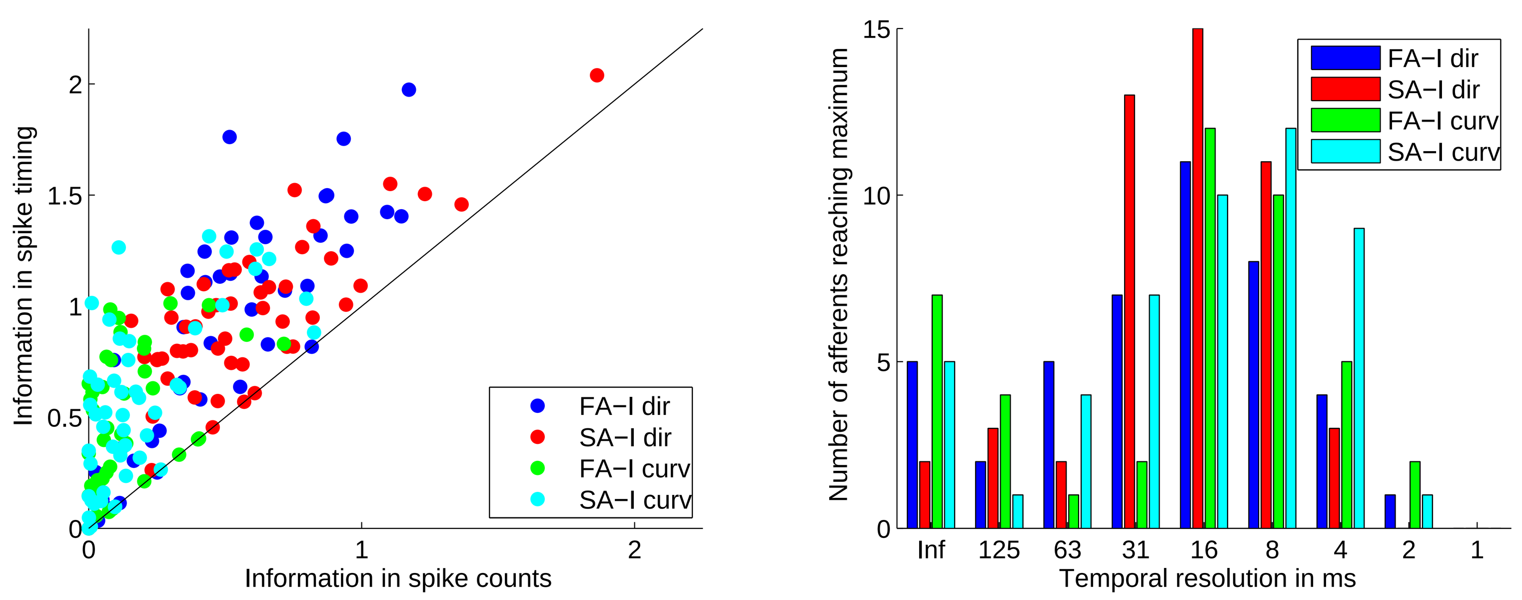

Figure 2: Left: Information in spike counts (abscissa) plotted against information in spike timing (ordinate). **Right:** Distribution of temporal resolutions at which each single afferent transmits maximal information.

Information contained in first spikes

First spike latencies [3] alone carry more than half of the information about force direction as compared to spike counts, and even more information about curvature than there is in spike counts (Figure 3). Subsequent spikes carry a high amount of information as well, although information declines for later spikes as temporal jitter increases.

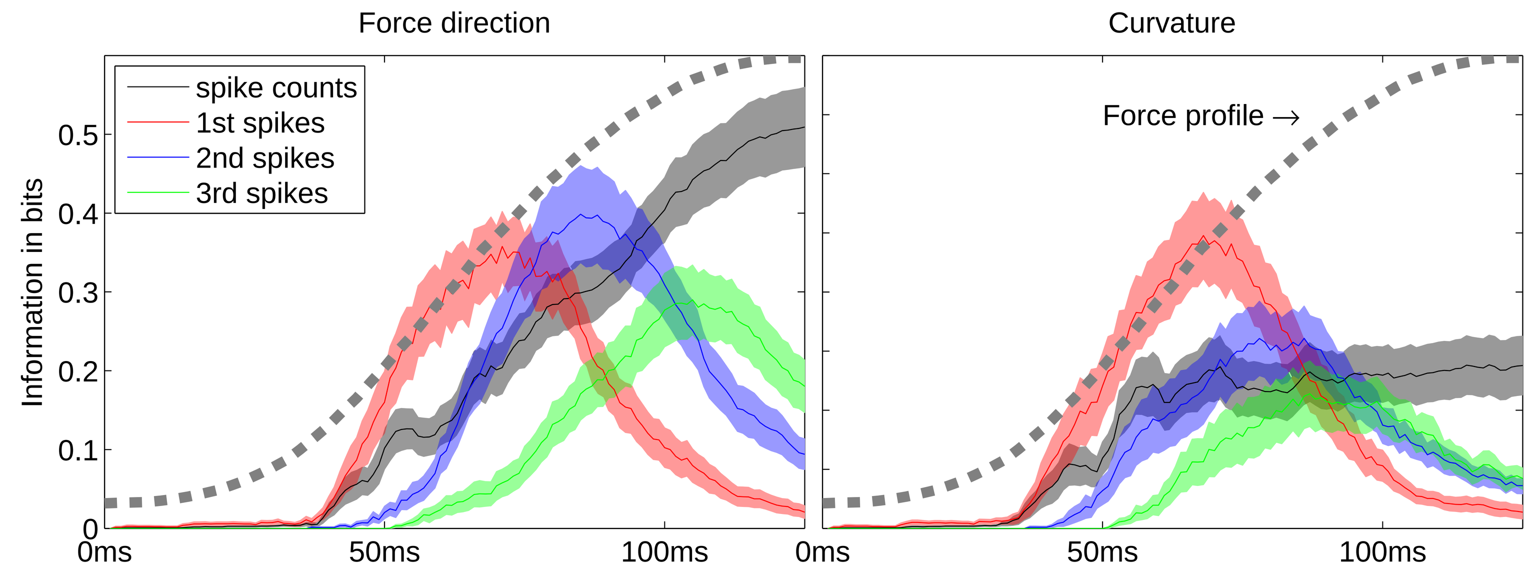

Figure 3: Average mutual information transmitted by the first spikes (red), second (blue), and third spikes (green) independently over time with a sliding window of size 30ms. Black lines correspond to the average information contained in spike counts. **Left:** Force direction. **Right:** Curvature.

Spatial distribution of information

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 4). This relationship was observed with both coding schemes, i.e. spike counts and first spike latencies.

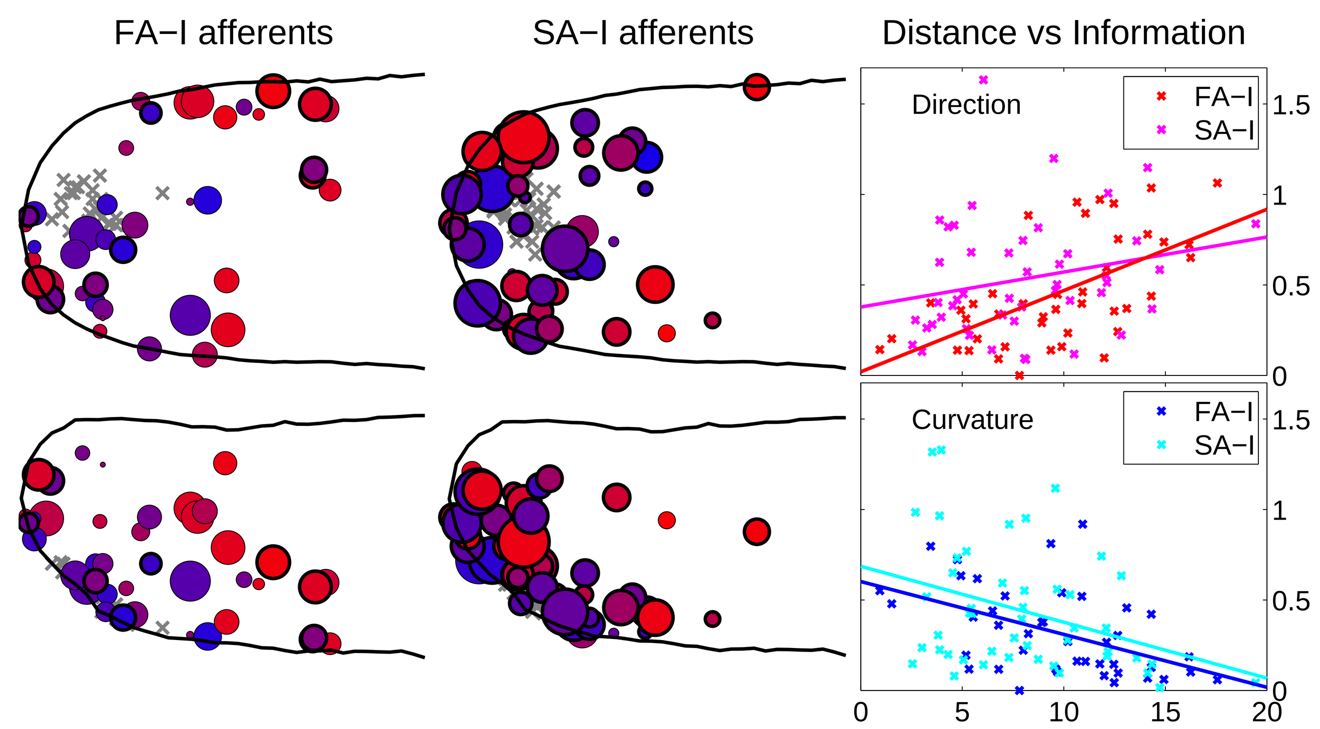

Figure 4: Left and middle column: Information about curvature (blue) and force direction (red) per afferent as projected onto the fingertip from above (top row) and the side (bottom row). **Right column:** Afferent distance from stimulation site vs information carried by that afferent about force direction (top) and curvature (bottom).

Synergy/redundancy between coding schemes

We examined whether the information transmitted by spike counts and first spike latencies in single afferents was independent, redundant, or whether there were even synergistic effects. We found that for force direction, afferents close to the stimulation site showed low synergistic information, whereas afferents farther away showed some redundancy (Figure 5). On average, the information in both coding schemes appeared to be mainly independent.

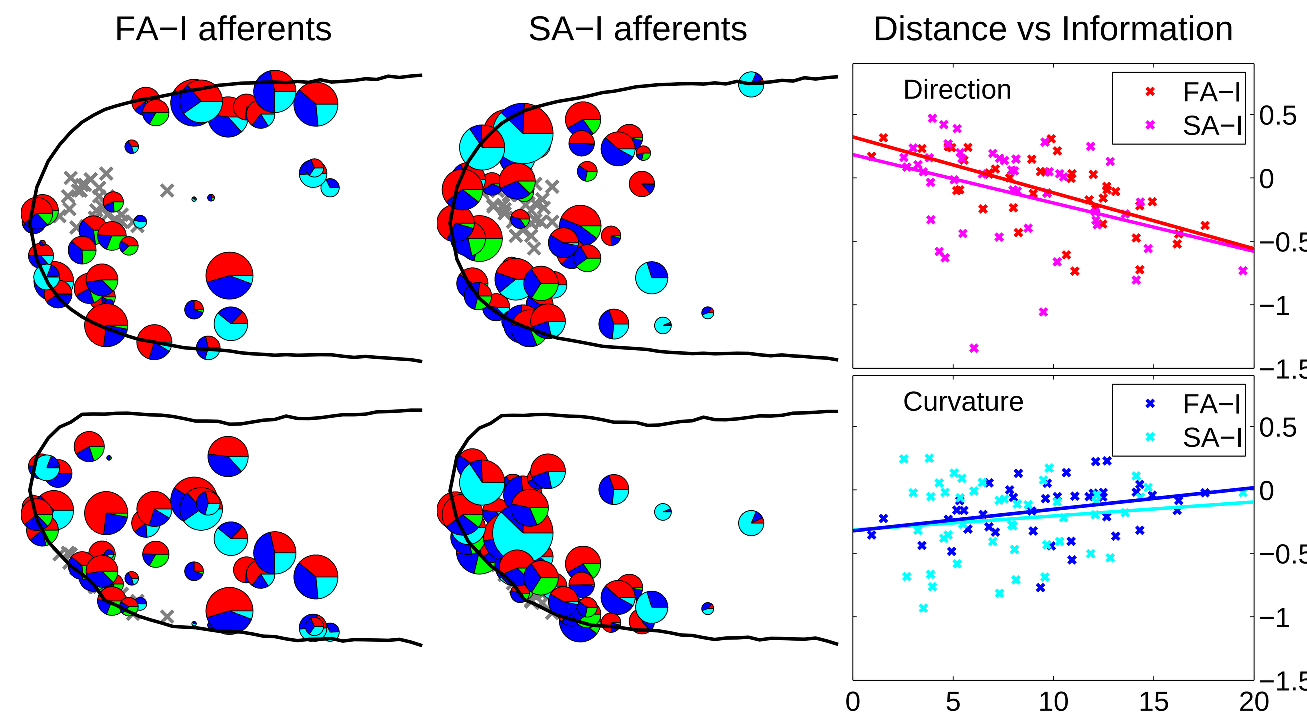

Figure 5: Left and middle column: Information about force direction in spike counts (dark blue) and first spike latencies (red). Redundant information in shown in light blue and synergistic information in green. **Right column:** Afferent distance from stimulation site vs synergy (positive values) and redundancy (negative values) for force direction (top) and curvature (bottom).

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.
- Information conveyed by spike counts and first spike latencies seems to be mainly **independent**, which indicates that there are different mechanisms of **encoding** information at work.

References

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[3] Johansson RS & Birznieks I, *Nat Neurosci* 7(2):170–177, 2004.

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