A computational counterexample to the need for sophisticated tactile sensing when learning to manipulate

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Tactile feedback is considered to play a critical role in skill acquisition and adaptation, influencing grasping, force modulation, and object manipulation (Wilson et al., 2016; Cienfuegos et al., 2024). This assumption has driven the engineering approach of emphasizing the inclusion of sophisticated tactile sensors in robotic and prosthetic hands (Abd et al., 2022; Dsouza et al., 2016). However, the ability of individuals to still manipulate objects effectively despite impaired sensation (such as when wearing gloves, in cold weather, or with soapy hands) challenges the longstanding belief that tactile input is necessary (Johansson and Cole, 1994; Johansson and Westling, 1984; Nowak et al., 2001; Pavlova et al., 2015). This study challenges the assumption that high-fidelity tactile sensors are always necessary for effective learning in robotic manipulation.

Using a simulated three-finger robotic hand, the study examines whether advanced 3D-force sensing provides a distinct advantage over simpler tactile modalities such as Normal-force, Binary-contact, and No-tactile sensation. Additionally, by employing unsupervised clustering, we tested whether different levels of tactile feedback produce different learning trends.

The study extends previous research on in-hand manipulation simulating a robotic hand interacting with a ball under four different tactile conditions: No-tactile, Binary-contact, Normal-force, and 3D-force (Ojaghi* et al., 2024; Mir et al., 2024). The learning process is conducted using Proximal Policy Optimization (PPO), a widely used RL algorithm. Two experimental scenarios are explored: a Baseline condition where the task of lifting and rotation remains constant during the learning period, and a Curriculum learning condition where we start with lift and add rotation as a second subtask to the second half of the learning. After collecting 60 trials from each sensory input condition, we aggregate all the progressions of learning as a time series–from all tactile sensory input for each scenario–over each episode and run it over a two-level K-means clustering approach to cluster progressions of learning.

Surprisingly, higher-fidelity tactile sensors (i.e., 3D-force) do not necessarily improve learning outcomes; and learning can happen even in the absence of tactile sensory input (i.e., No-tactile). In fact, Binary-contact sensors performed comparably to 3D-force sensors, suggesting that basic contact information can be sufficient for effective learning. Furthermore, the clustering analysis revealed that distinct learning trends emerged across all types of tactile sensory input, demonstrating that tactile fidelity alone does not determine learning success. Future work is needed to clearly establish for which tasks and environments this applies—and if so—which, when, and whether sensory information is needed during different phases of the learning process.

Justification Statement: The study's findings have implications for neurorehabilitation and assistive robotics by reevaluating the role of tactile feedback in motor learning and skill reacquisition. Our results suggest that rehabilitation technologies, such as prosthetic devices and haptic training systems, may not always require high-fidelity tactile sensors. Instead, structured training protocols and adaptive learning strategies (i.e., the curriculum and other feedback) may also promote learning and recovery outcomes. These insights contribute to the broader understanding of how sensory feedback influences motor learning, with applications in both robotic control and human rehabilitation.

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