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Measurement of Touch Interaction Cues in Discriminating Soft Fruit

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***Abstract*—Touch interaction cues help inform our sense of compliance. Efforts to ascertain the most relevant cues are mostly done with materials such as silicone-elastomers, foams, and robotic devices. It is unclear how well these engineered substances approximate the intrinsic material properties of ecologically compliant objects. Herein we study human tactile interactions with a natural object, that of soft plum fruit varying in ripeness; an organic substance associated with everyday tasks. An ink-based method was used to mark the finger pad to capture contact interactions, and instrumented load cells and non-contact laser sensors capture imposed force and displacement. In human-subjects experiments, participants discriminated plums grounded to a table (single finger) and held in a pinch grasp (index and thumb). The results indicate that contact area and force relationships vary per trial. Touch force and finger displacement also vary but significantly differ between the plums. In two-finger pinch, discrimination improved slightly. Compared to the single-finger case, the flatter finger pad contacted the plum, opposed to the fingertip, and led to larger and slightly more distinguishable contact areas. This work demonstrates a new technique for quantifying cues in human discrimination of natural objects, and articulates a path forward in working with such objects.**

I. Introduction

In our activities of daily living, we frequently interact with soft and compliant objects. For example, we might judge the ripeness of a fruit such as a peach, plum, or avocado. In more specialized environments, physicians may distinguish tissue and ducts from fat and bone. On-going efforts are refining our understanding of the physical and perceptual cues that help encode our sense of compliance. Distinct efforts have focused upon skin deformation and surface contact [1], [2], proprioception [3]–[5], as well as exploratory strategies [6]. Most of these studies use man-made materials, e.g., silicone-elastomers, foams, and robotic devices to stand-in for ecological materials. This is done because of the difficulty of acquiring, controlling, and quantifying the properties of naturally occurring soft objects such as animal or plant tissue, both from sample to sample and over time. However, to truly understand our sensory system, we must study interactions with objects for which it has been so finely tuned.

Very few human interaction studies have focused upon ecological stimuli. Among those, Katz (1938) studied bakers in their occupational interactions with dough and like substances, breaking down dimensions such as stickiness and elasticity [7]. Others have employed fabrics [8], written practical manuals to educate fruit and vegetable selection, and assessed visual and touch perception of the shape of bell peppers [9]. As well, robotic applications have sorted, grasped, and manipulated fruits and naturalistic objects [10].

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II. Methods

The preliminary work herein studies physical contact interaction cues in the discrimination of a naturally-occurring compliant object, the plum. The plum ties to tasks of everyday living, is easily acquired, ripens reasonably quickly, is inexpensive to purchase, can be grasped in one hand, and has a smooth surface. Methods from prior works [2], [11] were adapted for used with the plum (Figure 1). In particular, an ink-based method was used to mark the finger pad to capture contact area, and instrumented load cells and non-contact laser sensors capture imposed force and displacement. Setups were built such that plums were both grounded to a table (single finger) and held in a pinch grasp (index and thumb). In the case of the latter, only contact area was retrievable. In a preliminary human-subjects study with three participants (2 females, 1 male, mean age = 22.33, SD = 0.58), two plums were employed, one riper than the other. Discrimination experiments were performed in addition to biomechanical experiments. Participants operated under their own active, volitional control of their movements. Several considerations in the experiment's design were made to accommodate the readily perishable and easily damaged fruit stimuli.

III. Results and Discussion

The work herein – to the authors knowledge – is the first of its kind to measure touch interaction cues with a natural ecological object, in particular fruit. Overall, we find that contact area per force was slightly higher for softer than harder plums, though there was considerable variance between repeated trials, and the number of participants and trials is too small to yet be conclusive (Figure 2A). In contrast, touch force and finger displacement differed significantly between plums (Figure 2B-E). Furthermore, when moving to two finger pinch, which is a more natural way of judging the ripeness of fruit in practice, discrimination improved slightly. Indeed, in judging ripeness differences between the fruit specimens, contact area, contact force, and finger displacement cues are likely used together to discriminate the plums.

In general, the cues utilized by participants to form compliance judgements of the plums seem to align with those from studies done with silicone-elastomers, foams and other non-natural objects. In particular, efforts by Drewing, et al. have shown that maximum force is a reliable cue used in discrimination of softness [12], and our group likewise has reported on force-related cues, including force rate [5], [11]. As well, contact area has for years been associated with judging changes in compliance [1], and more recently has been associated with proprioceptive cues [4].

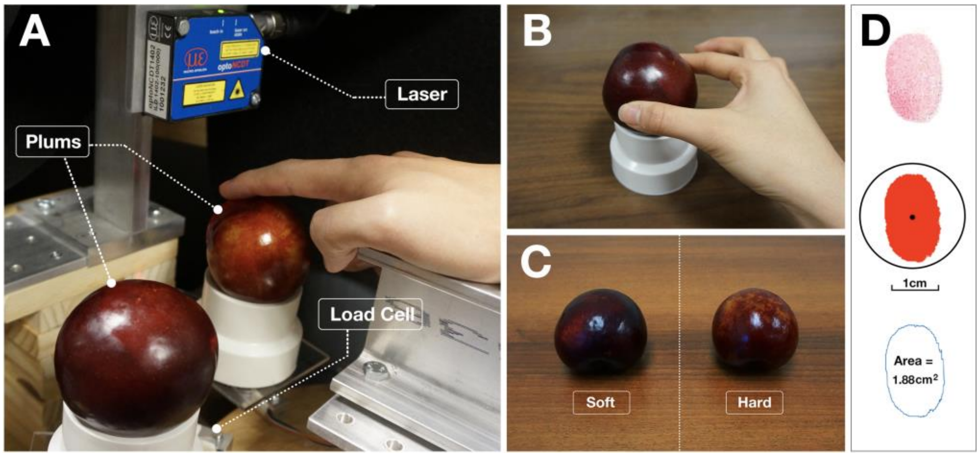

Figure 1. Experimental setup of test rig and ink-based contact area analysis of fingerprints. A) In the active touch setup for the single finger, table grounded condition, a set of two platforms is installed on a rotary table that can be rapidly rotated. The imposed force is measured by a load cell underneath each platform. The position of the fingernail is monitored by a laser displacement sensor. B) The two finger, pinch grasp condition where the plum is grasped above the pipe and held horizontally. C) Set of soft and hard plums. D) Plum contacted fingerprints are stamped onto paper and then digitized.

However, unlike interactions with engineered materials, we find that relationships between force and contact area appear to be largely inconsistent between repeated trials and the local region at which the fruit is pressed, despite consistency in participants' judgements. Further study with naturalistic objects may elucidate how their complex biomechanical relationships form a unified percept of material compliance. A robust and unique experimental design will be vital, due to the inherent difficulties in working with easily damageable objects that change over time.

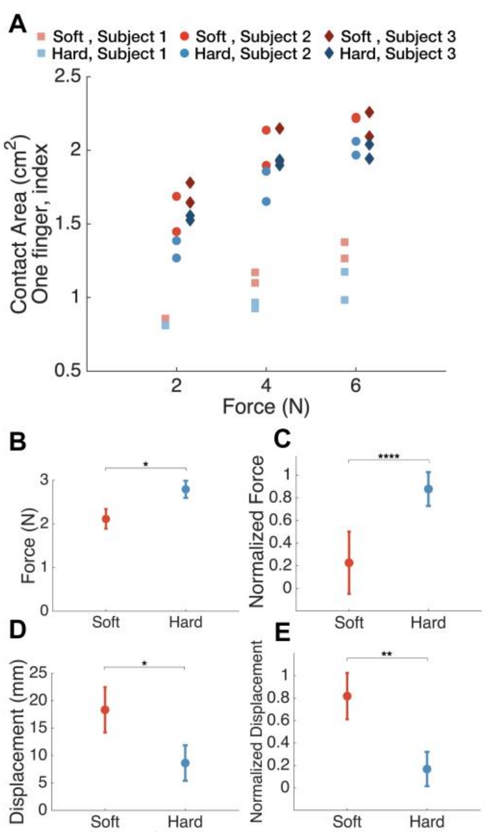

Figure 2. A) For the one index finger case are shown biomechanical relationships. B) Exemplar maximum force from one participant and C) normalized maximum touch force for three participants. D) Exemplar fingertip displacement from one participant and E) normalized fingertip displacement for two participants. Significance at $p < .05$, $p < .01$, and $p < .0001$ by paired-sample t-test. Error bars denote standard deviation.

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