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Perceived Softness of Composite Objects

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Abstract. What is the apparent softness of a grasped object composed of two compliant materials? Experimental data indicates that perceived softness of a composite object depends on how the object is grasped and how it is oriented. If the object is grasped with a precision grip using index and thumb, turning around the object leads to a consistent change in overall perceived softness. Namely, the composite object seems softer when the index is in contact with the more compliant material than when it is in contact with the stiffer material. Importantly, such a difference in perceived softness due to object orientation is not present when the precision grip is obtained by opposing index and middle fingers to the thumb.

Keywords: Softness, Compliance, Perception, Composite objects, Precision grip

1 Introduction

Object softness determines how object deform when forces are applied (i.e, like during manipulation). The brain can use sensory information about force and deformation to infer how soft the object is [4]. The softness estimate can be based on signals from one or multiple sensory sources [1]. Here, the case of multiple contact points with a deformable object is considered [2].

A hand grasp can have two or more contacts and can be potentially employed to obtain information about object properties, including softness. The information provided by each finger, however, need not be identical. Fingers could press more or less than others, the object weight could rests on one contact, sensor noise could be present, the contact points have different physical actuations and different characteristics, and so forth. Most importantly, the object material could differ as objects can be made up of multiple materials. Such objects are defined as “composite” [3]. With such discordant information the brain needs to determine whether the material changes across the object and then find a way to integrating the estimates into an overall percept of the object’s material (whether the object is uniform or not).

Here it is investigated how compliance is perceived when a composite object is held between the thumb and one/two fingers in a precision grip. This type of grasp is obtained by opposing the thumb to either the index or the index and middle fingers. Silicone cylinders whose material could either be uniform or differ at the two sides is presented so the fingers are in contact each with one side [6, 1]. Participants are asked to compare the overall softness of two objects or, unknowingly, of the same object grasped in opposite direction (i.e., turning around the object so that the surface in contact with the index and thumb switches). If perception was veridical, the expectation would be that changing the direction of the grasping and the number of finger should *not* affect perceived compliance. However, informal observations lead to a different impression and the goal here is to measure systematically whether this is the case. To test whether size of the object [1] or difference in compliance at the two sides [6] or fingers employed in the grasp influence the effect, we perform experiments with different objects and two types of precision grasp.

2 Method

Two psychophysical experiments are reported: In Experiment 1 the influence of different object sizes on softness perception was investigated; in Experiment 2, the number of fingers used for the exploration of the soft object was varied. In both experiments, participants performed a two-interval two alternatives forced choice task (2AFC). They reported which of two successively grasped and squeezed silicone objects was perceived to be softer. The objects were passed to the participants while they maintained the same hand position throughout the experiment (with thumb underneath and fingers spread ready to make a precision grip). Participants wore a pair of Plato Visual Occlusion Spectacles (Translucent Technologies inc.). Such glasses could be quickly switched from transparent to translucent by the experimenter. They allowed view of the hand and of the object when making the grip and they prevented view of the object deformation during squeezing movement. Such manipulation prevented participants from seeing the deformed shape of the cylinders. Participants were instructed to squeeze the object with a vertical precision grip as soon as the shutter glasses turned opaque. No constraints were imposed on the number of explorations and on the force of the squeeze. The exploration time for each object was limited to 3 seconds. The glasses were shut also before each grasp to prevented view of the experimenter choosing the objects.

Experiment 1 was conceived as a short test of the effect with only few trials to avoid inducing biases, response strategies, or adaptation. Objects of three sizes were tested (Small: radius 1.5cm, height 3cm; Medium: radius 1.5cm, height 4.5cm; Large: radius 2cm, height 6cm). Participants performed 29 randomised trials. First, they performed 5 comparisons of uniform objects and received feedback. This data was not analysed. In these trials the difference in compliance between the objects to be compared decreased from the extremes of the range in the first trial to minimal differences in compliance in the series. In the main experiment, participants performed 24 trials without receiving feedback, comparing either two uniform objects with minimal difference in compliance (12 trials, different pairs of objects from the ones used during training trials) or one composite object presented with two orientations. The two compared objects had the same dimension. Trials with composite objects were counterbalanced for order of presentation.

Experiment 2 tested grasping with different number of fingers (the larger objects used in Experiment 1 were employed). Participants performed 128 randomised trials without feedback where they compared either two different uniform objects or the same composite objects orientated differently (96 trials). Before the grasping, the experimenter said either "1" or "2" indicating how many fingers should be opposed to the thumb. In 1/4 of the trials the number of fingers for the grasping changed for the two objects (data not presented). Three 5-minutes breaks divided the experiment in four blocks of trials.

Ten participants took part in Experiment 1 and other 10 took part in Experiment 2. Participants in Experiment 1, which lasted 15 minutes, were recruited from the MPI Tübingen Subject Database and in return for their participation they received payment of 8 EUR/h. Participants in Experiment 2, which lasted 60 minutes, were undergraduate students recruited via the University of Birmingham research participation system (SONA) and received 6 GBP/h. Participants gave written consent before taking part in the experiment and they were naïve as to the purpose of the study. They were all right handed, reported not to have a history of sensorimotor disorders, had normal or corrected-to-normal vision. Experiments were undertaken with the understanding and consent of each participant, with the approval of the Ethik-Kommission der Medizinischen Fakultät am Universitätsklinikum Tübingen (Exp. 1), and of the STEM Ethical Review Committee of the University of Birmingham (Exp.2).

Seventeen cylindrical silicone objects with different compliances were made using Smooth-On EcoFlex 0030. Except for the size of some of them, they looked identical unless pressed against. Nine of these objects were "Small" uniform, 2 were "Large" uniform, 6 (2 for each size) were composed of two materials in the two halves along the main cylinder direction. The uniform objects were created by changing the silicone to hardener ratio (5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5) in the mixture so to obtain different compliances. They were used for training and as distractors during the experiments. The 6 composite objects (2 for each size) had either a silicone to hardener ratio of 3:1 on one half and 1:3 on the other (Low compliance difference), or 4:1 and 1:4 (High compliance difference).

3 Results

Participants' softness discrimination performance with uniform objects was flawless in Experiment 1 and near flawless in Experiment 2 (95%). As participants could discriminate these samples, it is likely that they notice the difference in softness at the two sides of the composite objects, as for all composite object the difference in compliance was higher than the difference between any two uniform objects.

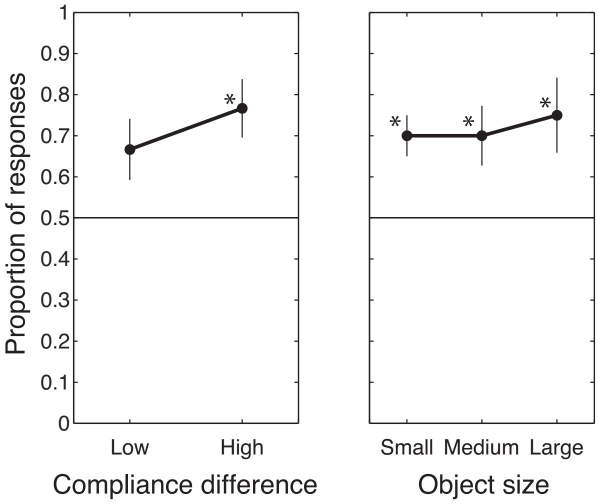

Fig. 1. Proportion of responses where composite objects were reported being softer when the compliant side was towards the index. Deviation from chance level means that participants consistently differentiated the two directions in terms of overall compliance. Responses higher than 0.5 indicate higher number of objects with the soft side towards the index to be softer than with the stiff side towards the index. The 24 trials are subdivided according to compliance difference at the two sides (12 trials per point) and for objects of different sizes (8 trials per point). Error bars are s.e.m. Asterisks indicate a significant difference from chance level.

Results obtained with composite objects in Experiment 1 are shown in Figure 1. Objects were explored with two orientations of index-thumb grasping and responses indicate a difference in responses. Participants preferentially reported the object grasped with the compliant side towards the index (and the stiff side towards the thumb) to be softer than the same object grasped with the the stiff side toward the index finger (compliant side towards the thumb). This tendency was found to be consistent in direction with the two magnitudes of compliance difference at the two sides, but the effect reached statistical significance only for the High compliance difference (single-sample two tailed t-test against 0.5 of the proportion of responses, p value is Bonferroni corrected for the two tests performed on each condition: Low $t(9) = 2.2$, $p = 0.10$; High $t(9) = 3.7$, $p = 0.0092$). The pattern of responses was significantly different from chance for all sizes of the object tested (t-test against 0.5 Bonferroni corrected: Small $t(9) = 4.0$, $p = 0.0062$; Medium $t(9) = 2.8$, $p = 0.044$; Large $t(9) = 2.7$, $p = 0.046$).

Results obtained with composite objects in Experiment 2 are shown in Figure 2. When participants used Index+Thumb, results replicate the tendency that was found in Experiment 1 to report the object to be softer when the soft side is in contact with the index at high compliance differences (t-test against 0.5 Bonferroni corrected, Low: $t(9) = 2.1$, $p = 1$, High: $t(9) = 8.3$, $p < 0.001$). When

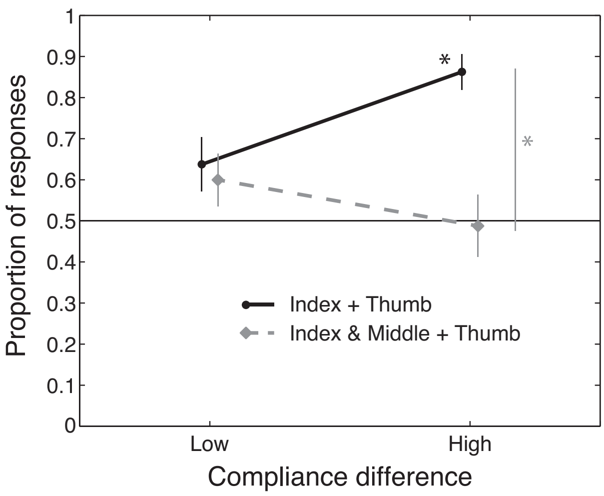

Fig. 2. Proportion of composite cylinder reported being softer when the compliant side was towards the Index finger or the Index&Middle fingers in Experiment 2. The two lines correspond to conditions where the exploration was done changing the number of fingers opposed to the thumb. Error bars are s.e.m.. Dark asterisk indicates significant difference from chance level, grey asterisk indicates significant difference between conditions.

participants used Index&Middle+Thumb this tendency is instead not present and responses are not different from chance (t-test against 0.5 Bonferroni corrected, Low: $t(9) = 1.6$, $p = 0.30$, High: $t(9) = 0.2$, $p = 1.0$). Proportion of responses does not change as a function of number of fingers with low conflict stimuli (paired-sample t-test Bonferroni corrected, $t(9) = 0.4$, $p = 1.0$), but does change with high conflict stimuli (paired-sample t-test Bonferroni corrected, $t(9) = 4.6$, $p = 0.0026$).

4 Discussion

The two experiments presented here investigate how softness judgments of a composite object are obtained. Despite the perceptible difference at the two sides, when asked to compare the overall perceived softness of objects participants judgements depend on grasping direction for objects with composed objects having high difference in compliance. With an Index+Thumb precision grip there is a tendency to decide about the stiffness by relying more on the information coming from the index finger (rather than the thumb). The same object is judged to have two different compliances depending on orientation. The pattern becomes significant only with large differences in compliance, which is consistent with the difference in response pattern due to the difference in compliance found in [3]. The response tendency does not disappear with any of the object sizes tested. Interestingly, the tendency to answer differently depending on orientation disappears with a Index&Middle+Thumb grasp. Such result points to the uniformity of softness discrimination performance with changes in object size when expressed in terms of Young's modulus [1].

Softness perception is obtained from the tactile information available at the different contact points and from the proprioceptive information about the change in object deformation due to the force applied [7, 4, 1]. Several factors could be in place to create the change in perceived softness from these sources of sensory information. A general account for the effect could be to think at the two contact points as two sensors whose estimates are integrated by weighting sensory information according to reliability [3, 5]. One could argue, for example, that there is a preference for the information coming from the index finger and thus interactions where the index is in contact with the more compliant side lead to a softer percept than when the index is in contact with a stiff object. Such a result has been found also for interactions where only proprioceptive information about softness was available [3]. To explain the lack of an effect in Experiment 2 it could be hypothesised that the weighting of the information from index&middle fingers is more similar to the one of the thumb than what happens using only the index and thumb.

The higher weight given to the sensory information coming from the index finger might be due to the passive and stabilisation role of the thumb in this grasp configuration. In this view, the index finger explores the object actively and thus receives more weight. Moreover, due to gravity the weight of the object lies on the thumb which could introduce noise and thereby make the information the thumb receives less reliable. Although this hypothesis could explain the presence of the effect with Index+Thumb grip, it does not predict a lack of effect with Index&Middle+Thumb grip.

A related possibility is that the index finger moves more than the thumb and thus it is given more weight [3]. To explain the lack of an effect in Experiment 2, the joint use of index and middle finger should lead to smaller finger movements compared to the index alone. Further studies are required to verify whether this is the case.

Another factor that could lead to a higher reliance on information coming from the index finger is the amount of activated cutaneous receptors. Although it may seem that using index and middle finger instead of only index should sum the number of available neural signal, it could be that the higher contact area actually decreases pressure [6]. This should thus lead to a less reliable signal and to less weight in the integration.

Finally, it should be considered that the area of the fingers in contact with the object is not equal. Contact area is an important factor in softness perception: The Young's modulus of a material is inversely proportional to the area where the force is applied and this value is a strong determinant in softness sensitivity [1]. This is because the change in contact area during the indentation is an important signal for softness perception [6]. Because of the stabilisation role of the thumb, the area of the index finger is minimal and leads to highest Young's modulus values. As participants must account for the two sources of tactile information at once, they should integrate the two modulus values. If this is the contact area is the critical factor, then the sum of the two moduli with the index in contact to the compliant side must be higher than when in contact with the stiff side. Additional investigation is required to determine whether this is the case.

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