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The influence of material cues on early grasping force

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Abstract. The object of this study was to see whether differences in texture influence grip force in the very early phase of grasping an object. Subjects were asked to pick up objects with different textures either blindfolded or sighted, while grip force was measured. Maximum force was found to be adjusted to suit the differences in coefficient of friction, confirming earlier results. Surprisingly, statistically significant differences in grip force were already present as short as 10 ms after touch onset in the blindfolded condition, despite the fact that only haptic information about the texture was available. This suggests that the haptic system is very fast in identifying a texture's friction.

Keywords: Texture, Friction, Grasping

1 Introduction

When grasping an object in order to pick it up, a number of conditions need to be satisfied: The grasp should be stable, so as not to push away or rotate the object; The grip force (the force acting perpendicular to the touched surface) should not be too high in order to avoid crushing the object; And the force should also be not too low, which could cause the object to slip. In fact, when holding an object, humans are very skilled in adjusting the grip force so as to just prevent slipping [4]. When a held object starts slipping but has not yet actually moved, this 'microslip' is detected by the skin receptors and the grip force is adjusted automatically and immediately. In this way, the grip force is accurately tuned to the load force (the force acting on the object parallel to the touched surface) and the surface friction. That it is friction, and not texture, that determines the grip force was shown in an experiment in which grip force was measured and the friction of the touched surfaces was manipulated while the texture stayed the same. The grip force was mainly determined by the coefficient of friction [2].

The question now presents itself: How do we determine this coefficient of friction, and how do we adjust our grasping force to it when picking up an object? When an object is held, the microslip cues mentioned above give information about the coefficient of friction, but these are not yet available in the very early phase of the grasp. It could be that there exists a learned association between the properties of a surface texture and its coefficient of friction. When a texture is seen, an estimate of the friction could be made before the object is touched, based on earlier experience. Combined with an estimate of the mass of the object, grip forces could be adjusted to match the object [3]. This should already manifest itself in the grasping force just after contact is made with the object. Moreover, if visual information is not available, humans should rely on haptic information for their estimate of the surface friction. The question then is, how fast can they recognise a texture by touch and adjust their grip force to the associated coefficient of friction?

In the present paper, we investigate how the grasping force during the very early phase of picking up an object, depends on the material and thus the texture of the object. We do this by measuring the force used by human subjects when picking up objects of equal mass but different textures. An effect of material on grip force, independent of surface friction, has been found in an experiment in which subjects picked up objects of equal mass made of different materials, by a handle [1]. For the initial lifts, the grip forces were scaled to the *expected* mass of the objects based on a visual estimate of the material's density (material-weight illusion). This might cause a possible confound in our experiments: if subjects' grip forces are not only influenced by the expected coefficient of friction of the texture, but also by the expected mass, it might be difficult to disentangle the two effects. However, the authors also found that after a few lifts, subjects scaled their grip forces to the *actual* weight of the stimuli. Based on this information, we can avoid the confound by disregarding the first few trials for each stimulus. Furthermore, to assess the respective roles of visual and haptic information, we employ two conditions: one with haptic and visual cues available, and one with only haptic cues available.

2 Method

2.1 Subjects

Twelve right-handed subjects (four males) were recruited. They ranged in age between 20 and 27 years (mean: 23 years). All had normal or corrected-to-normal vision and reported no tactual deficits. Prior to the actual experiment, but after instruction, they signed an informed consent form. They were paid €8 for their participation in the one-hour experiment. The experiment was approved by the Ethical Committee of the Faculty of Human Movement Sciences, VU University Amsterdam.

2.2 Stimuli and apparatus

Stimuli were six solid steel cubes of $40 \times 40 \times 40$ mm, with a mass of 0.500 kg. This relatively dense material was chosen to make the stimuli quite heavy, encouraging subjects not to apply more force than was necessary in order to prevent slipping. The stimuli were clad on five sides using different, visually distinct materials: Leather chamois, ribbed cloth, coarse sandpaper, metallic-like plastic

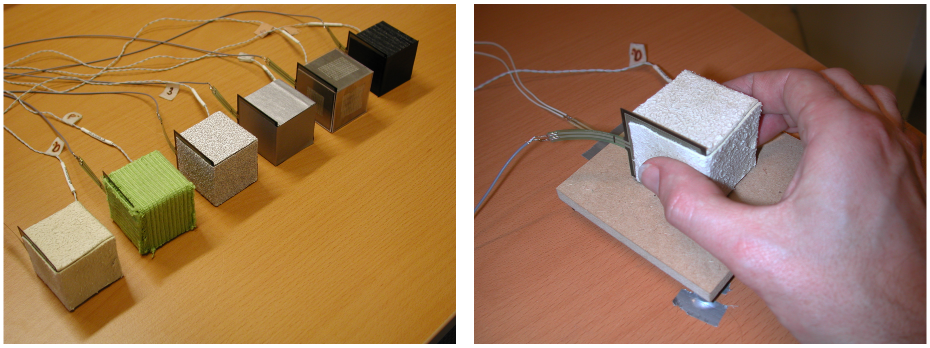

Fig. 1. Left: Photograph of the stimuli. The edges of the force sensors can be seen protruding from behind the textures. **Right:** Photograph of a hand grasping a stimulus sitting on the platform.

film, acrylic glass, and wood-like plastic film, as shown in figure 1 (left). The backside was unclad, but this was never visible to the subjects, nor did they touch it. On the left side, between the texture and the steel, was a 38×38 mm force sensor (FSR 406, Interlink Electronics) to measure thumb force. Using a voltage divider comprising a 10 kΩ resistor and a 5 V bias voltage, the sensor's resistance was read out with a 12-bit ADC board (PCI-1200, National Instruments), sampling at 1 kHz. Each of the six sensors was read out separately.

Before grasping, the stimuli were placed on a 15 mm high platform. During the visual condition, the other stimuli were hidden from view by a curtain. The room was lighted uniformly using overhead fluorescent lighting.

2.3 Procedure

Calibration Each force sensor was calibrated for each subject separately, in order to account for differences in thumb size and shape. The stimuli, with the force sensor up, were placed on top of a digital weight scale (Mettler Toledo Spider A6, precision 0.001 kg) interfaced with the computer. Subjects were asked to place their thumb on top of the stimulus, while looking at the force displayed in a graph on the computer screen. They were asked to gradually increase the pressure on the thumb until the indicator reached the right side of the graph, which corresponded to 3 kg (29 N). The voltage over the sensor was registered. An example of a calibration measurement is shown in figure 2. An empirical function of the form

$$f(x) = a(\exp(bx) - 1) + c(\exp(dx^2) - 1) \quad (1)$$

was fitted to the data, with a, b, c, and d free parameters. This relation is not based on any physical sensor property, but seemed an excellent fit to the data. In total, 72 sets of parameter values were obtained (12 subjects $\times$ 6 stimuli). For the coefficients of determination we found $R^2 > 0.994$. Fitted parameters differed

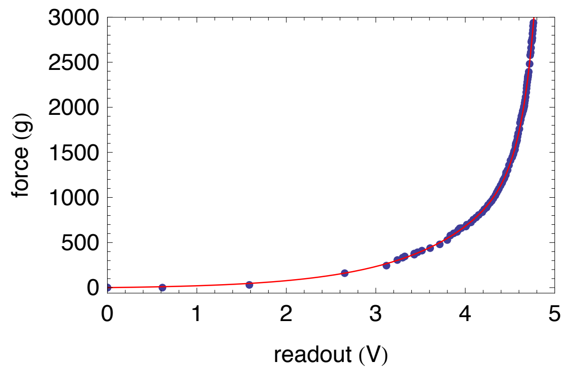

Fig. 2. Example of a force sensor calibration measurement. The force measured using the digital scale is plotted as a function of the voltage readout of the force sensor (dots). The solid line is a fit to the data.

slightly between sensors and between subjects. Between subjects, coefficients of variation ranged from 0.11 (for parameter d of ribbed cloth) to 3.4 (for parameter c of wood-like pastic film) for the different sensors and fit parameters.

Experiment The experiment consisted of two conditions: one blindfolded, with only haptic information available, and one sighted, with both haptic and visual information available. The blindfolded condition was always performed first, in order to prevent subjects from forming a visual-haptic association prematurely. Both conditions consisted of 60 trials, ten for each stimulus, in random order. In each trial, one stimulus was placed on the platform, and an auditive signal cued the subject to grasp the stimulus between thumb and fingers, pick it up, lift it a few centimeters and set it down again. They had to use their thumb on one side and one or more fingers on the other side of the object, as shown in figure 1 (right). No instructions were given on what force they should use, but they were told they should grasp the object as they would in everyday life. Thumb grasping force was measured for 2 s (2000 samples), including the onset of the force and the maximum force during the highest vertical acceleration. The two conditions (120 trials) took between 35 and 50 minutes to complete (mean: 40 minutes).

2.4 Analysis

Using the per-subject calibration, the measured voltages from the force sensor were converted to forces. A 21-sample moving average was applied to each force trace to eliminate electrical noise. For each trial, the maximum force was determined. Also, the onset of the grasp was detected by determining the moment that the force exceeded 0.01 N. Then, the force at 10 ms after onset was determined. In addition, the force trace was differentiated and the maximum force

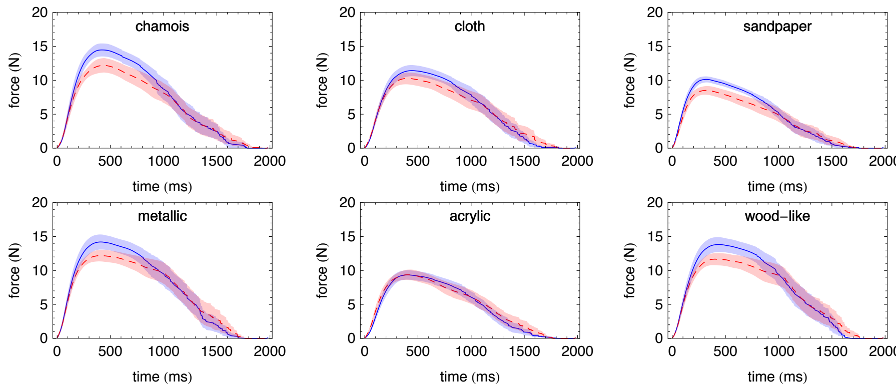

Fig. 3. Grip force as a function of time while picking up objects with different textures, averaged over subjects. Blue solid lines show the blindfolded condition, while red dashed lines show the sighted condition. The shaded areas correspond to the standard error of sample mean.

rate (maximum of the derivative of the force) was determined. Maximum force, force after 10 ms, and maximum force rate were averaged over trials for each texture, condition, and subject separately, excluding the first two trials for each texture in order to eliminate any confound introduced by the material-weight illusion [1]. Since no visual information is available to anticipate the object's friction before touching it in the blindfolded condition, whereas there is in the sighted condition, we expected different effects of material in the two conditions. Therefore, the results were not analysed using one single 6×2 ANOVA. Instead, one-way repeated-measures ANOVAs were used in each condition separately to determine whether there was an effect of material on these measures. If sphericity was violated according to Mauchly's test, a Greenhouse-Geisser corrected value is reported. Furthermore, Bonferroni-corrected paired t-tests were used to check for an effect of visual information for each material separately.

3 Results

Force traces averaged over subjects are shown in figure 3. As can be seen in the figure, there are differences between the maximum force for the different materials. These differences are statistically significant both for the blindfolded condition ($F_{2.4,27} = 17,\ p = 8.7 \times 10^{-6}$) and for the sighted condition ($F_{2.3,26} = 11,\ p = 0.00021$). For chamois, sandpaper, metallic and wood-like plastic film, the maximum force in the blindfolded condition seems higher than in the sighted condition, but these differences are not significant when Bonferroni correction is applied to the t-tests.

When we look at the forces only 10 ms after contact is made, as shown in figure 4, we see that in the very early phase of the grasp, already differences in force are visible. Interestingly, these differences are significant for the blindfolded

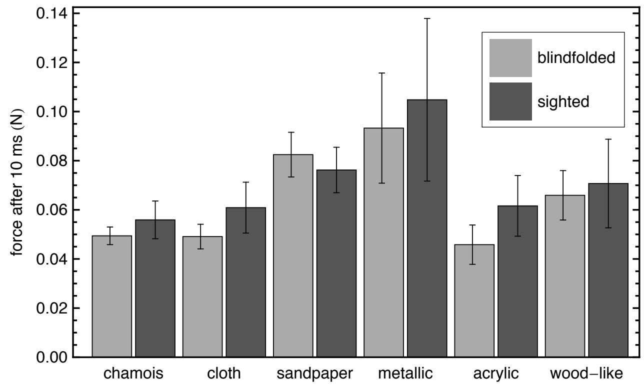

Fig. 4. Grip forces 10 ms after contact for the different textures and conditions (without or with visual information), averaged over subjects. The error bars indicate the standard error of the sample mean.

condition ($F_{1.8,20} = 5.0,\ p = 0.021$), but not for the sighted condition ($F_{1.9,21} = 2.0,\ p = 0.17$). Also no significant effect of condition on grip force at 10 ms is found for any of the six textures.

When comparing figures 3 and 4, we see that those materials that are grasped with the highest *maximum* force, are not necessarily those with the highest *initial* force. However, when looked at on the level of individual trials, the correlation between maximum force and force after 10 ms is small but significant ($R = 0.076,\ n = 1440,\ p = 0.0039$).

Maximum force rate ranges from 72 to 108 N/s. Significant effects of material on maximum force rate are found, both in the blindfolded condition ($F_{2.6,29} = 9.9,\ p = 0.00021$) and in the sighted condition ($F_{5,55} = 7.6,\ p = 0.000017$).

4 Discussion

The differences found in maximum force for the different textures confirm that humans adjust their grip force to attain the necessary frictional force to prevent slipping, as was found earlier [2]. It also confirms that indeed our stimuli differ in their coefficient of friction, as was our intention in creating these stimuli.

The relative large mass of the objects ensures that subjects have to use quite a bit of force to pick them up. For this reason, it is advantageous for the subjects to not use more force than necessary, instead of using the same force for all objects out of convenience. The differences in maximum force suggest that this is indeed what they did.

The low (though significant) correlation between maximum force and force at 10 ms after making contact suggests that it may not be just the friction coefficient that determines the initial grasping force, but other aspects (roughness, pleasantness) may also play a role. New research should confirm this.

It was our hypothesis that without visual information, subjects would not be able to anticipate the friction of the texture, and could only adjust their grip force after they had recognised the material through touch or after they detect slippage when trying to lift it. Since 10 ms is a very short time in terms of such perceptual processes, it is quite surprising that already after that amount of time, statistically significant differences were found in the grip force in the blindfolded condition. Since it is impossible for high-level cognitive processes to be involved on such short time scales, it might be that a low-level feedback loop is responsible for the observed effect. It should be noted that since the moving average used in the analysis takes into account data from $-10 \ldots +10$ ms around each point in time, the significant differences might be from up to 20 ms after contact is made.

It is equally surprising that the forces at 10 ms did not differ significantly in the sighted condition, even though subjects had ample time to plan their force before touching the stimulus, based on visual information. Additional analyses revealed that significant differences were found also in the visual condition from 40 ms onward. In short, grip forces are already adjusted to object friction during the very early phase of picking up an object, also when only haptic information is available, demonstrating the impressive speed of the human haptic system. It could be that when visual information is not available, humans pay more attention to their haptic system for identification of the texture's friction, enabling them to adjust their finger force faster than when visual information is available.

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