What Is It Like to Be a Rat? Sensory Augmentation Study

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Abstract. The present study examined the human ability to learn a new sensory modality, specifically “whisking”. An experimental apparatus containing artificial whiskers, force sensors, position sensors and computer interface was developed. Twelve participants took part in an experiment containing three tasks: pole localization in the radial dimension, roughness estimation, and object recognition. All tasks were performed only through use of the artificial whiskers which were attached to participants’ fingers. With little or no practice humans were able to localize objects, recognize shapes and assess roughness with accuracy equal to or greater than that of rats in equivalent tasks, though with longer times. While the number of available whiskers significantly affected shape recognition, it did not affect radial localization accuracy. Introspection by participants revealed a wide range of motor-sensory strategies developed in order to solve the tasks.

Keywords: Sensory augmentation, vibrissa, perception, whiskers, object recognition, localization.

1 Introduction

The question “what is it like to be a bat” was raised by the philosopher Thomas Nagel in a classical paper carrying that name [1]. The work argues for the unavoidably subjective nature of perception and experiences. The rats’ vibrissa (whisker) system, which has no human equivalent, is a part of their somatosensory system. The vibrissae are extremely sensitive [2]; their sensitivity is comparable to that of primate fingertips [3]. Rats can independently move their whiskers across surfaces to make fine tactile discriminations [3, 4]. For many years researchers have been looking into the precise nature of information conveyed by the whiskers to the brain (see [5-10] for current reviews). However, the more information we gain about rats’ vibrissa system, the more Nagel's claim becomes relevant, since we humans lack first-hand knowledge of a whisker-like system. In order to gain “first hand” knowledge of the vibrissa system, we augmented the sense of touch in human volunteers by creating a new sense of 'whisking' and tested the volunteers in a variety of perceptual tasks. An advantage of studying ‘whisking’ in human subjects, in the study of the mechanisms of sensory perception, is that we already possess good models of sensory coding in the rat. Specifically, we have acquired a basic understanding of the computational constraints on

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several of the algorithms and on some of the neuronal implementations that area involved in the execution of active tasks by the rats' vibrissa system.

Sensory augmentation is a developing area of research in which human sensation is augmented in order to create new sensory capabilities (e.g. sensing magnetic fields [11]). This approach can give insights into both the way the brain learns to use a new sensory modality and the subjective experience of the learner during this process by measuring the change in performance capabilities with practice.

Our experimental goals were: (1) to study mechanisms of perception in an augmented tactile sense, and (2) to gain information through human introspection about plausible internal processes in a whisking rat. Preliminary results on 3 different tasks are presented.

2 Methods

2.1 Apparatus

Twelve adult human participants were dressed with long elastic rods on their fingers that mimic rats' whiskers (Fig. 1).

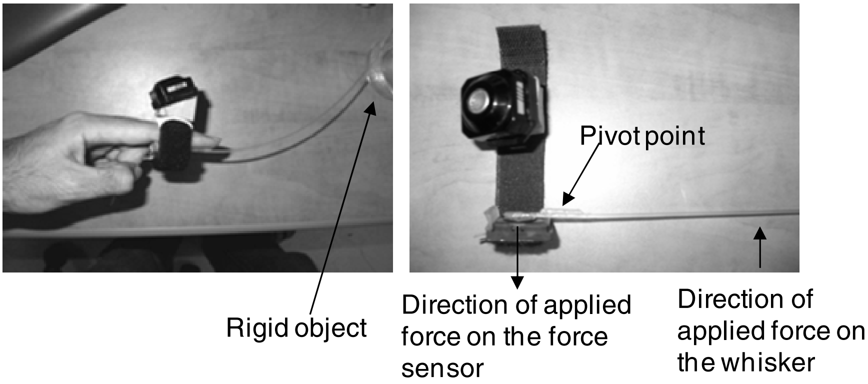

Fig. 1. Left: The artificial whiskers apparatus used in the experiments. The whisker is pressed against a rigid object. Right: The "button" of the v-scope system and the plastic whisker attached to force sensor.

The whiskers were made from transparent PVC rods that were molded into a conical shape by heating and stretching. The diameter of each whisker changed gradually from 1.8mm at the base to 1.2mm at its end and their length was 34.5cm. The whiskers' stiffness was slightly softer than that of a drinking straw, and they did not bend under their own weight when held horizontally. The base of each whisker was glued to an electronic force sensor (FS20 load cell, measurement specialties, USA). The force sensor (along with the whisker) was glued to a narrow Velcro ® strip which was used to connect the apparatus to the finger (see Fig. 1). A small piece of PVC rod was glued to the whisker base in front of (and in contact with) the finger pad. The movements and forces of the whisker were transmitted by the PVC rod to the entire length of the finger pad – this arrangement simulated the interaction between the whisker and its elongated follicle in rats. The rod also served as a pivot point – i.e. when the finger pad was pressed against it, the base part of the whisker was pressed against the force sensor. Therefore, the forces applied by the whisker on the fingertip could be recorded via the electronic force sensor. In addition, a 3D tracking "button" was connected to the Velcro® on the opposite side of the force sensor. The button is part of the v-scope tracking system (V-scope, LVS-11-pro, Litek, Tel-Aviv, Israel). Each button's position (and therefore the fingers' positions) was tracked via the system every 30ms with a spatial resolution of 0.1mm. The force sensors were connected to a computer via an analog-to-digital card (DaqBoard/100, ioteck, USA). In the experiment room, a video camera was positioned on the ceiling and an upper view of the human volunteer performing the different tasks was captured. All electronic monitoring devices (whisker force sensors, position trackers and video camera) were connected to a single computer. Data acquisition was handled through a specialized real-time program written in Matlab.

2.2 The Tasks

Three perceptual tasks, mimicking published rat whisker-related tasks, were chosen: pole localization in the radial dimension [12, 13], roughness estimation [2, 3], and 3D shape recognition [14]. The experiment consisted of 2 sessions of ~1 hour each on two different days (24-48 hours between sessions). In each session, all tasks were tested. Half of the participants performed the tasks on the first day with one whisker per hand and the other half performed the task with two whiskers per hand. On the second day the number of whiskers per hand was switched between the groups. In the two whiskers per hand condition the whiskers were affixed to the middle and index fingers, and in the one whisker per hand condition they were affixed to the index fingers. During all tasks the participants were blindfolded and wore earphones playing white-noise superimposed on classical music in order to block any assistance by auditory cues. In all tasks, objects were positioned manually by the experimenter in a predefined counter balanced order. Tracking of the position of fingers (whiskers) and force was performed only in the radial localization task for technical reasons. Oral feedback ("right" / "wrong") was given after each trial. Out of the 12 participants, only 8 performed the task twice.

2.2.1 Radial Discrimination Task

Two Small Tables were positioned to the right and left of the participant, equidistant from the midline of the chair where the participant sat. A metal pole wrapped with cotton cloth (in order to eliminate contact sounds between poles and whiskers) was positioned on each table (fig 2).

Poles were located in different radial distances and the participant's task was to determine which pole was located closer to him or her along the radial axis (i.e., which pole is closer to the base of the whisker). No further instructions on how to solve the task were given.

The difference in position between the poles at the beginning of each trial was 16 cm. This difference was stepped down in logarithmic increments following a staircase paradigm as in Knutsen et al 2006 [15]. The radial position differences between the poles were rounded-up to the nearest integer number in centimeters, and therefore the smallest difference tested was 1 cm (1 cm was also the measuring error in the experimental apparatus). For all distances, the poles were within reach only of the whiskers and not within reach of the participant’s fingers. Before the beginning of the session the participant was given *one* practice trial (of 16 cm difference).

2.2.2 Roughness Estimation

The participant sat in front of a table. In each trial he or she needed to palpate a pair of sandpaper sheets and to say which one was more “rough”. The sandpapers' roughness measure, the grit, represents the average number of particles per inch of sandpaper. Within the range we used, the lower the grit, the rougher was the sandpaper (the diameter of the particles and the intervals between them were larger). The grits used in these trials are 120 vs. 1200, 60 vs. 24, 60 vs. 1200 and 1200 vs. smooth transparency sheet.

2.2.3 Three-Dimensional Shape Recognition

Four 3D geometrical objects (pyramid, prism, small box and elongated box, Fig. 2) made from cardboard were first presented visually to the participants. Then the participants were asked to palpate the objects with their whisker(s) and determine which of the four objects was placed on the table in front of them (the shapes were presented in a random order).

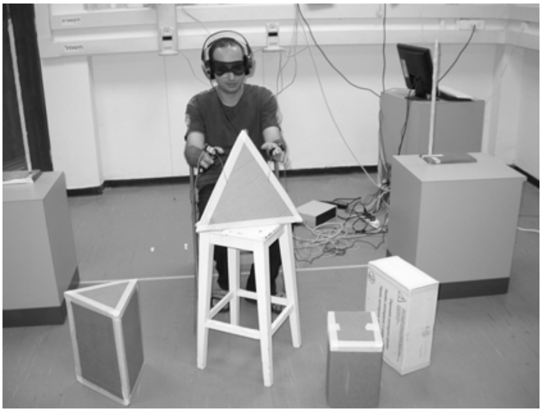

Fig. 2. The 3D shape recognition task. The two poles used in the radial discrimination task are seen on both sides of the participant. Notice, two ‘towers’ of the v-scope tracking system are seen on the wall behind the participant.

3 Results

Interestingly, with little or no practice humans were able to localize objects and estimate roughness as accurately as, and in some cases even better than, rats in equivalent tasks. Here we present the psychophysical results and introspective reports by the participants. The sensor data (force and location) have not yet been analyzed.

3.1 Radial Discrimination Task

In this task participants were asked to tell which one of the two bilaterally presented poles was closer to them in the radial dimension. We did not find any effect of the number of whiskers per hand on participants' performance or psychophysical threshold (paired T-test, n = 8, P-Value = 0.82). Comparison of the performance between the first and the second session shows a weak experience effect. In the second session the thresholds were lower, but with borderline statistical significance (paired T-test, n = 8, P-Value = 0.053).

At the beginning of the first session, the participants found it difficult to know which pole was closer to them (notice that participants were not given any instruction on how to solve the task). Thus, at the beginning of the first session participants were in search of correlations between the correct answer in the trial and some physical or sensory variable mediated through the whiskers (via motor action). Interestingly, the 12 participants reported 5 different strategies for correlating the radial distance with some motor-sensory behavior. The strategies, according to self-reports of the participants are summarized in Table 1.

Table 1. Strategies used by participants in the radial discrimination task according to participants' introspection, and possible analogous rats' strategies

Human strategy (correlation between radial distance and…)	#	Analogous rat strategy
Force-moment at the whisker base.	7	Force-moment at the whisker base.
Force-gradient along the finger-pad area touching the whisker.	2	Force-gradient along the whisker follicle.
Amplitude of whiskers vibration following contact with the poles.	1	Amplitude of whiskers vibration following contact with the poles.
Detach time during synchronized forward whisker movement that passes the poles.	1	Detach time during synchronized forward whisker movement that passes the poles.
Detach time during synchronized retraction whisker movement in the coronal plane (movement from fully stretched hands to hands close to body).	1	Detach time during lateral head movements (non synchronous comparison).

The first 4 strategies can be employed in a similar manner by humans and rats while the 5th strategy must be implemented differently. There is evidence suggesting that radial distance is encoded in rats by the force-moment at the base of the whisker [16-18]; interestingly, the majority of participants chose this strategy by themselves. However, in contrast to the rats' behavior in the experiments reported by Krupa et al. [12], human participants in our experiments did not improve their performance with additional whiskers (as mentioned above). Multiple whisker palpation might be helpful in radial localization in rats due to the limited resolution of single mechanoreceptors [19], which might not be the case in human skin sensation.

All in all, participants' performance was very good in the test (average threshold around 2.5cm). Two participants even reached the minimum discrimination distance in the system: 1cm. These threshold values are better than rats' ones [12] when taken in relation to the distance between the two poles (2.5 / 190 vs 3 / 65) and comparable when taken in relation to whisker length (2.5 / 34.5 vs 3 / 50).

3.2 Shape Recognition Task

In this task, participants were asked to identify geometrical shape through palpation by the whiskers. Human success rates (Fig. 3) were comparable to those of rats [14]. In contrast to the radial task, the number of whiskers did significantly affect the results. In sessions performed with two whiskers per hand participants were more accurate relative to sessions performed with one whisker per hand (Fig. 3, paired T-test P-Value<0.05).

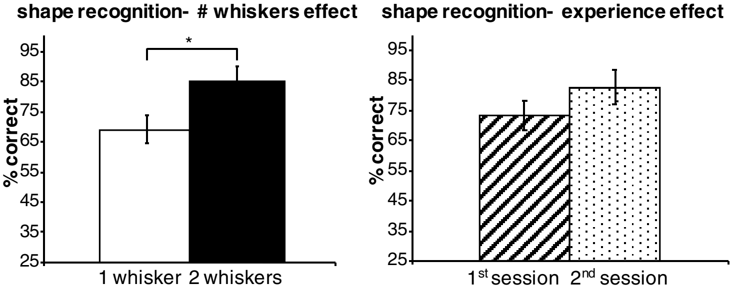

Fig 3. Success rate (percent correct) in the shape recognition task as a function of whiskers number (left) and experience (right). The error bars represent the s.e.m.

As in the radial discrimination task, the experience of the participants seems to affect their performance (Fig. 3). However, in this task the effect was small and was not found to be statistically significant.

3.3 Roughness Estimation

In this task all participants in all conditions were 100% correct – all of them were always able to discriminate correctly the rough from the less rough sand-paper in less than 30 seconds of palpation. Obviously, the task was too easy for humans. This is in contradiction to rats, which even in a much easier task – of discriminating totally smooth surface from a sandpaper – do not reach 100% correct performance [2]. Note however that rats rarely spend more than half a second on such tasks, possibly because 100% perfection is rarely their obsession.

4 General Discussion

In this research we have shown a proof of principle. Humans were able to learn to use a new sense of 'whisking', and to use this new sense to solve different perceptual tasks. The perceptual thresholds reached were as good as, and sometimes even better than, rats in similar tasks. Using humans as a 'model animal' for rats can provide insights, via introspection, on perceptual strategies that might be employed by rats and mice – insights that cannot be obtained otherwise. Although rodent and human touch biomechanics differ, the motor-sensory strategies, and the use of re-afference and ex-afference signals might be comparable [9, 20]. Studying tactile augmentation in humans can facilitate development of efficient sensory augmentation and substitution devices for the blind and deaf. Another consequence of this kind of research is gaining knowledge of how the brain learns to use a sense. When performing research on existing human senses, humans can be considered experts in their use. With such high level expertise, it is almost impossible to unravel *why* participants tend to use a specific motor-sensory strategy and *how* this strategy was developed. Introspection in this case cannot help, since perceptual learning of regular tasks by existing senses occurs in the early stages of life and thus cannot be reliably reported. In contrast, sensory-augmentation both facilitate the isolation of sensory variables, as has been previously shown [21, 22], and allows for the most preliminary processes of learning to be recorded, analyzed and self-reported while they occur.

In the radial task, participants initially searched for a strategy that correlated the sensory information transmitted by the whisker, and the oral feedback given by the experimenter. Once such correlation was found, participants did not change strategy, but tried to improve performance by sharpening the relevant sensory parameters, using their developed strategy. Whether this is the case with rodents is not yet clear.

Unlike in the radial task, shape recognition was facilitated by the addition of a second whisker to each hand. This difference may derive from the fact that the shape recognition is a 3D task, in which case simultaneous scanning provides relative spatial information crucial for shape recognition. The radial task is one dimensional task for which relative information between whiskers is not crucial. Bilateral palpation of frontal objects, which is occasionally observed in freely exploring rats and mice (unpublished observations), probably further facilitates shape recognition.

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