Haptic discrimination of paper

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Introduction

This chapter describes a study on the haptic discrimination of different types of plain paper. The experiment is designed to replicate features of a 'banknote' scenario in which it may be possible to identify a counterfeit on the basis of only a few seconds contact. Multidimensional scaling (MDS) techniques are used to investigate the perceptual dimensions involved in the discrimination task. A related study of tactile perceptual space is summarised in Appendix 1.

It is an everyday experience to handle paper – turning the page of a book, opening mail, handling a banknote – and it takes only a short time to assess the paper in terms of its characteristic 'feel'. (See Lederman and Klatsky's investigation [1] of manipulation strategies for obtaining information about objects in general.) The present study investigates some of the perceptual processes which are involved in making such assessments, particularly in relation to features which are significant in the handling of banknotes. (In the United Kingdom, the distinctive feel of banknotes is officially recommended as an indicator for the detection of counterfeits, and there is anecdotal evidence that counterfeits may indeed be detected in this way.) Such features might include gross physical parameters such as paper thickness and stiffness, as well as parameters which relate to surface texture.

There have been few previous studies on the perception of thickness or stiffness for material in the form of thin sheets. Thickness discrimination might in principle be based either on direct perception of thickness (for example, when holding a sheet between finger and thumb, in terms of joint angle) or on perception of stiffness (which is determined both by the thickness of sheet and the mechanical properties of the material). Such discrimination has been investigated by John, Goodwin and Darian-Smith [2] and Ho [3]. The author of the latter study proposed an explanation of results from both investigations on the basis that, when sheets are sufficiently thin to deform under finger contact, thickness discrimination is based primarily on perception of the curvature of the deformed sheet.

The majority of published material on tactile perception of surface texture concerns the response to well-defined artificial surfaces such as gratings [4–6] or embossed patterns [7]. There are a few studies involving the surface texture of everyday objects, which is often difficult to describe objectively. In an early study, Katz [8] describes an experiment on the tactile discrimination of 14 types of paper (chosen with a wide range of properties and each intended to be clearly discriminable from the others) and develops the concept of *Modifikationen* (qualities), which provide scales on which surfaces may be rated. Hollins, Faldowski, Rao and Young [9] studied the dimensionality of 'natural' tactile stimuli such as wood, sandpaper, velvet, etc., and suggested that three perceptual dimensions were involved: one corresponding to roughness/smoothness, one to hardness/softness and a third tentatively ascribed to 'springiness'. In further studies [10–12], Hollins and co-workers have provided evidence for a sticky/slippery dimension, and demonstrated the role of Pacinian corpuscles in the tactile perception of surface roughness. In an experiment involving discrimination of a very wide range (124 types) of flat surface, Tiest and Kappers [13] identi-

fied four perceptual dimensions, none of which was well matched to measured values of surface roughness or surface compressibility.

In the case of paper, although it is possible to characterise the surface by means of a range of parameters such as mean height of surface features, typical separation of surface peaks, etc., it is not easy to predict how these parameters will contribute to aspects of perceived surface texture. Lyne, Whiteman and Donderi [14] found three main factors which influenced the perceived quality of paper towelling – rigidity, surface softness and embossment pattern. However, the tactile features of paper towels are rather different from those of the typing or photocopying paper used in the present study.

The literature also contains a variety of studies relating to 'fabric hand', i.e., the way in which a textile may be evaluated in terms of its characteristic feel. Kawabata [15] relates fabric hand to various measured properties of the textile: tensile properties, shearing and bending properties, thickness and compression properties, surface roughness and surface friction. Picard, Dacremont, Valentin and Giboreau [16] describe experiments which suggest a four-dimensional perceptual space for textiles stretched over a flat support.

The present study was designed to replicate some features of a 'banknote' scenario in which it is necessary, when handling a sequence of notes, to identify a counterfeit on the basis of only a few seconds contact (and generally without the advantage of comparing two notes directly). The intention was to investigate a set of relatively similar stimuli, with a view to establishing which aspects are important for discrimination of small differences between papers. Subjects were required to handle rectangles of various types of paper, each for a few seconds. The rectangles were presented in sequences of three, in an 'odd-one-out' task. Discrimination scores between the various papers were obtained, as the basis for constructing a multidimensional perceptual space for the papers. Broadly similar experimental strategies are described by Hollins, Bensmaia, Karlof and Young [10], involving tactile investigation of a wide range of everyday surfaces, and by Cooke, Steinke, Wallraven and Bülthoff [17], involving haptic exploration of object shape.

Method

Subjects were 12 unpaid volunteers: graduate students in the age range 22–27, nine male and three female. Two of the males were left-handed; the remainder of the subjects were right-handed.

Each stimulus was a rectangle of paper with dimensions 135 mm × 69 mm, corresponding to the size of a common UK banknote. Stimuli were produced from different types of plain white paper – one of these was rag paper of the type used for banknotes (in an unprinted state and consequently with somewhat different handling properties to actual banknotes) and the rest were intended for typing or photocopying, acquired from several stationery stores. 28 different types of paper were considered; ten were discarded after an initial inspection because of various anomalies, such as large surface features related to the watermark. From the remaining 18 papers, ten which appeared in an informal assessment to be perceptually similar were selected for use, including the rag paper. (Similar papers were selected in order to focus on the known acuity of discrimination in this context; this choice also facilitates the determination of discrimination indices d', as described below.) The selected papers varied in thickness from 98–131 μm and in area density from 73–102 gm m^{-2}. A large number of rectangles were prepared from each of the ten selected papers.

Procedure

The experiment used an 'odd one out from three' format with a three-alternative forced choice (3AFC), in which three samples of paper were presented in sequence to the subject, two being of the same type and the other of a different type. Subjects were instructed to pick up each sample with one hand (from a tray on which the experi-