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Hand movements and hemispheric specialization in dichhaptic explorations

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Abstract. Dichhaptic testing has been widely used to assess lateralization in tactile processing. The rationale of dichhaptic testing is that simultaneous exploration of two objects enhances competition between relevant cortical areas in the right and left hemispheres. The synchronization of hand movements in a dichhaptic situation was investigated to determine whether both hands explore the two shapes simultaneously. Fourteen men were tested with the aid of a dichhaptic intermodal task. Tactile stimuli were composite shapes and the activity of each hand was assessed through analysis of hand contacts on each part of the shape. Only 20% of the total exploration time was devoted to simultaneous investigation of the two shapes. In addition, it was found that (i) the recognition accuracy was greater when the target shape was explored by the left hand compared with the right, and (ii) the left hand touched a greater number of parts of the stimuli than the right. Overall, comparison of the present data with those from a previous, monohaptic, task with the same stimuli suggests an advantage of dichhaptic over monohaptic testing to demonstrate laterality differences in accuracy of recognition. However, it is suggested that this advantage is due to cognitive factors rather than to competition between homologous cortical areas.

1 Introduction

The past 20 years have seen the emergence of an important literature on lateralization of haptic processing. A crucial contribution to this field was the seminal study by Witelson (1974) who employed, for the first time, a dichhaptic procedure. The dichhaptic procedure is the haptic analogue of the dichotic listening task initially conceived by Broadbent (1954) and later employed by Kimura (1967). In the classic dichhaptic paradigm, each hand of the subject simultaneously explores a different object; the objects are hidden from view. Visual figures are then displayed to the subjects who are asked to identify the stimuli which they have just tactually inspected. The rationale of the dichhaptic paradigm is that simultaneous tactile input would produce a bilateral hemispheric activation and competing arousal of relevant homologous areas in the left and right hemispheres. Such competition would modulate or even inhibit interhemispheric information exchange through the cerebral commissures. It is assumed that the study of dichhaptic perception is a better way to investigate hemispheric specialization in normal subjects than is the use of monohaptic explorations.

Since the initial work by Witelson (1974, 1976), the dichhaptic procedure has largely been employed to assess hemispheric differences in active touch. In an extensive review of the literature, Summers and Lederman (1990) reported 64 sets of data (out of 114 on haptic perception) concerning dichhaptic perception of not obviously representative shapes. An inconsistent picture emerges from this review of studies of dichhaptic perception. In some studies, a left-hand advantage has been found (eg Webster and Thurber 1978) ie there was a greater accuracy in the recognition phase when the left hand was used to haptically inspect the object than when the right hand was used. In contrast, several reseachers failed to report any lateral bias (eg Cranney and Ashton 1980), although others provide evidence for a right-hand advantage

(Yandell and Elias 1983). Dichhaptic testing also provided unclear results concerning sex differences in hemispheric lateralization (Summers and Lederman 1990).

In a review of the literature, Verjat (1989) has proposed that during the dichhaptic task the two hands might not conduct haptic explorations simultaneously. When the instruction is to perform a dichhaptic exploration it is, in fact, possible that the subjects might place one hand on each shape but nevertheless explore the two shapes sequentially. In other words, although the two objects are contacted, only one hand is moving at a time and the objects are explored in alternation. If such strategies are used, then the basic requirement of the dichaptic paradigm—competitive bilateral stimulation—is violated.

We have recently designed a system that empirically examines the issue of dichhaptic strategies. With this apparatus, we record the form and duration of hand contacts on composite nonrepresentative shapes (Fagot et al 1992). Use of this system in a monohaptic testing procedure has revealed that hand differences in exploration exist even though the two hands have comparable accuracy levels (Fagot et al 1993). Specifically, we have found that the left hand of right-handed men consistently felt a larger surface area of the object than did the right hand. The present study is an attempt to investigate exploratory strategies in a dichhaptic situation. We focus our attention on the synchrony of hand movements in order to verify whether the dichhaptic situation really entails a simultaneous haptic exploration of the two objects. In addition, we will present accuracy data and measures of hand span in order to compare the results of the present dichhaptic study with those previously obtained from monohaptic testing (Fagot et al 1993).

2 Methods

2.1 *Subjects*

Fourteen men were tested in this experiment (mean age = 25.5 years, range 20–32 years). Prior to the study, subjects had indicated by self-report that they had no sinistral parent and preferentially used their right hand in each of the six items of a laterality questionnaire. The questions included: which hand the subject used in writing, drawing, throwing a ball, brushing teeth, hammering, and use of a racket.

2.2 *Apparatus and stimuli*

The apparatus has been described by Fagot et al (1992). It is depicted in figure 1. Briefly, it consists of an aluminium box (33 cm × 33 cm × 20 cm) with two stimuli located inside. The front of the box comprises of two motorized adjacent vertically sliding doors, each 7 cm × 14.5 cm. The rear of the box is fitted with two vertical side-by-side panels (16.4 cm × 15.4 cm). Each panel has a central aperture (6.6 cm × 6.6 cm) in which one stimulus is placed 10 cm above the base of the box and 5 cm back from its front. A distance of 9 cm separates the closest sides of the two objects. The box apparatus was connected to a PC computer via an A/D converter.

A total of twelve nonrepresentative stimuli were used during testing. Stimuli were composed of eight adjacent metallic cubes (1 cm × 1 cm × 1 cm each; see figure 2) fixed on a 6.5 cm × 6.5 cm lexan baseboard. The junctions between the cubes were not haptically discernible. As is shown in figure 2, stimuli were designed according to five rules: (i) they were constructed with a maximum of 5 cubes in a row; (ii) they were asymmetric; (iii) their contours comprised 10 angles and 10 sides; (iv) they were not mirror images of other stimuli employed during testing; and (v) they were not rotations of other stimuli employed during testing.

Each cube forming part of a stimulus was electrically insulated from the others and was polarized at +5 V. Provided that the subject was electrically earthed, any hand contact on a cube shifted the voltage of the touched cube (from +5 V to 0 V). The duration and location of these electric variations caused by hand contacts were recorded by the computer and provided data for the investigation of haptic strategies [see Fagot et al (1992) for other technical details].

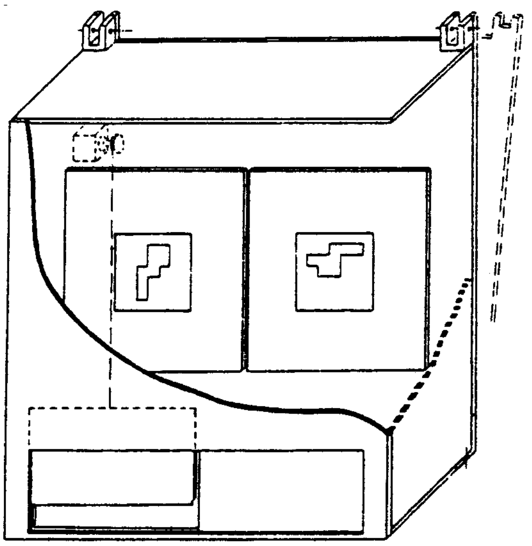

Figure 1. Apparatus used in the experiment. See text for details.

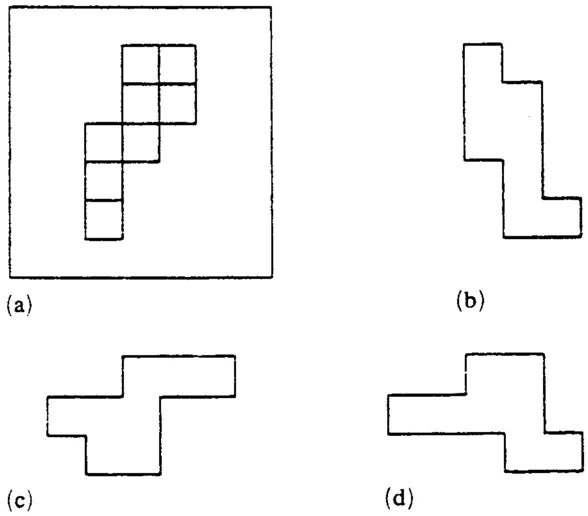

Figure 2. Illustration of the composite stimuli used in the study: (a) the eight cubes and the lexan baseboard on which the cubes were fixed; (b–d) outlines of some of the other stimuli used as they were presented in the visual recognition display.

2.3 *Procedure*

The subject sat at a table facing the apparatus. He was earthed by strapping an electrode to one ankle. A vertical opaque board (110 cm × 65 cm) prevented him from viewing the experimenter and all components of the system other than the front of the box. Trials began with a warning tone and, 1 s later, the two sliding doors were opened. The subject then inserted both hands inside the apparatus to perform a digital exploration of the two shapes simultaneously (ie dichhaptic exploration). The subject was allowed 10 s to explore the shapes, with the exploratory time starting when at least one cube of either of the two shapes was contacted. At the end of the 10 s exploratory time, a warning tone was sounded and the doors were closed. The experimenter immediately presented the subject with a visual recognition display (21 cm × 30 cm) containing the outline drawings of three different shapes, each measuring 5 cm × 5 cm maximum. One of the three drawings represented one of the two stimuli that had been touched. The other two were part of a different set of twenty-four drawings. The subject was required to designate the drawing corresponding to the shape he had haptically explored. On the recognition display, one drawing was on the left side, another was on the right side and the third was centrally positioned. The location of the 'correct' drawing on the display was balanced across trials. The subject responded by raising his left, right, or both hands to indicate the position of the drawing which he recognized as the stimulus shape (left side, right side, or central position, respectively, on the display). No time restriction was imposed nor was feedback for the subject's response given.

Subjects performed twenty-four experimental trials with an intertrial interval of approximately 2 min. Each stimulus was used four times during the testing of each subject and was explored twice by each hand. A given stimulus was the 'key' stimulus, that is the one to be recognized, on one trial per hand. The tactile stimuli were always presented in the same orientation. The order of stimulus presentation was identical for each subject. This order was selected to avoid (i) the presentation of the same stimulus on two consecutive trials and (ii) the use of the same pair of stimuli twice. Before testing, subjects were allowed two practice trials with two pairs of stimuli that were different from the twelve experimental shapes.

2.4 *Dependent variables*

We distinguished two types of dichhaptic exploratory strategies. The first, type I, involves simultaneous displacement of both hands on the shape. The second, type II, involves contact of both hands on the shape but one hand at least is not moving for a minimum of 500 ms. For each hand, mobility was assessed by changes in the pattern of cubes touched. Two additional variables were recorded for analysis: accuracy and span. Accuracy was the total number of correct responses in the recognition phase of the task. Span was a measure of the number of cubes simultaneously touched on average during one trial. These two measures were made independently for each hand.

3 Results

3.1 *Descriptive analysis of dichhaptic exploration*

Haptic investigation was permitted for 10 s and hand contact was detected on average for 9995 ms (SD = 13 ms). During investigation of the shapes, dichhaptic explorations (type I and type II) lasted on average 9342 ms (SD = 385 ms). Thus, subjects maintained contact with the two shapes for nearly the entire duration of the trial.

It was found that 80.2% (mean = 7494 ms, SD = 1638 ms) of the time devoted to dichhaptic strategies corresponded to type II explorations, that is explorations in which at least one hand was not moving. Type I explorations were observed for 19.8% of the total dichhaptic time (mean = 1848 ms, SD = 1456 ms). Figure 3 represents the percentage of time spent in type I explorations for each subject. The difference between times spent in type I and type II explorations was significant (two-tailed paired t test, $t_{13} = 6.9$, $p < 0.001$).

An analysis of the immobility periods showed that they lasted 1986 ms (SD = 854 ms) on average. A separate analysis for each hand demonstrated immobility periods totalling 2105 ms (SD = 1229 ms) for the left hand and 1866 ms (SD = 691 ms) for the right hand. Between-hand comparisons revealed no significant effect (two-tailed paired t test, $t_{13} = 0.86$). Thus, the total period of static-touch time was comparable for the left and right hands.

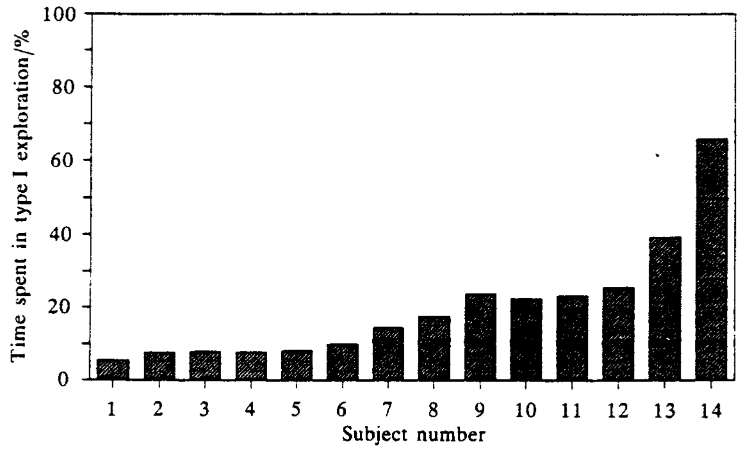

Figure 3. Time occupied in type I explorations (ie with both hands active) as a percentage of the total duration of dichhaptic exploration (type I and type II) for each subject.

3.2 *Laterality effects*
The overall accuracy was 77.1% (SD = 14.5%), which indicates that the subjects' success rate was significantly above chance rates of 33.3% correct. The two hands differed in their capacity for recognition. When the key shape was inspected by the left hand, recognition accuracy was significantly higher (81.5% correct responses) than when it was touched by the right hand (72.6% correct responses). This difference was found to be significant (paired two-tailed t test, $t_{13} = 2.26$, $p < 0.05$). Hand differences were also found in terms of span. The average number of cubes touched simultaneously was 4.58 (SD = 0.81) when the left hand investigated a shape. For the right hand, the average number of cubes touched was 4.44 (SD = 0.87). A paired two-tailed t test revealed this difference to be significant ($t_{13} = 2.23$, $p < 0.05$).

3.3 *Intercorrelation analyses*
Correlational analyses (Pearson-product moment correlation) were conducted between the respective amount of individual type I or type II exploratory strategies and the overall performance. For the type I strategy, there was a negative but nonsignificant correlation between both measures ($r_{12} = -0.32$). For the type II strategy, this correlation was positive but also nonsignificant ($r_{12} = 0.37$).

4 Discussion
The most important finding from this study is the demonstration that, in a dichhaptic task, the two hands do not simultaneously inspect the stimuli. Detailed recording of variations in hand-shape contact reveals that, during nearly 80% of the exploration time, only one hand was moving while the other hand remained static. Only 20% of the time was devoted to dichhaptic explorations of type I, with the two hands actively inspecting the shapes simultaneously. Historically, the dichhaptic paradigm was

designed to enhance competition between the hemispheres by way of competitive stimulation. Our results clearly demonstrate that these conditions are not always met in the course of dichhaptic exploration. However, it could be that, in a dichhaptic task, the proportions of type II and type I processing are dependent on the spatial nature of the stimuli. For example, the discrimination between two mirror-image shapes could induce more bilateral movements, and thus more type I processing than would the discrimination of two different shapes. Lomov (1966) found that subjects performed simultaneous bimanual movements when the shape to be haptically explored was symmetrical. When the shape was asymmetrical, other patterns of bimanual movement appeared—one hand palpating the form while the other was inactive.

Our analyses revealed a positive correlation between the amount of type II processing and overall accuracy. In contrast, a negative correlation was found between the amount of type I processing and accuracy. These results suggest a greater accuracy when the hands attend to the two shapes sequentially than with a simultaneous palpation of the shapes with the two hands. However, the lack of significant results precludes any firm conclusion with respect to the effect of the processing type on accuracy.

Two additional findings are noteworthy. First, we found significantly better accuracy in shape recognition when the left hand touched the shape than when the right hand was used. It should be recalled that in a previous study using a monohaptic procedure with the same stimuli, male subjects did not show such an asymmetry. Second, consistent differences between hands appeared in the manner in which shapes were felt: the left hand had a marginally but consistently greater span than the right. A similar effect was found in our previous monohaptic study.

A comparison of accuracy differences found in the present study and those of our previous, monohaptic, one (Fagot et al 1993) shows that the dichhaptic situation is more sensitive to lateral differences than is the monohaptic situation. This conclusion is in agreement with Witelson's (1976) model of hemispheric specialization. However, with some interindividual differences (see figure 3), subjects seem to avoid parallel and bilateral hand movements on the stimulus shape. Thus, the effect of dichhaptic presentation on accuracy can hardly be accounted for on the basis of competition of homologous areas in the left and right hemispheres.

Complementary to the previous hypothesis, it has also been suggested that the simultaneous palpation of two objects inhibits linguistic encoding (Witelson 1976), at least when the shapes have no immediately obvious meaning. This inhibition would enhance the observed hemispheric asymmetry. This explanation also seems unlikely to be valid because subjects rarely inspected the two objects at the same time. Thus, they can use linguistic strategies to characterize the shapes that are, basically, touched in a sequential manner.

Other cognitive explanations can be advanced to explain the results. For example, as suggested by Verjat (1989), the sequential analysis of the shapes would involve some powerful information-storage mechanisms. In this framework, it can be argued that the right hemisphere is better at storing or recalling spatial information than is the left hemisphere. There is also the fact that in a dichhaptic situation the subject had to deal with two objects. This basic characteristic of dichhaptic testing increases the complexity of the task and the attentional resources that are recruited. We suggest that the respective weight of these variables, as well as intersubject differences, could account for the lack of left-hand advantage reported in several dichhaptic studies in which 'nonsense' shapes were used (eg Adams and Duda 1986).

In contrast with the accuracy data, when span is considered, a consistent laterality effect was found in dichhaptic and in monohaptic testing. In both types of studies we found that the left hand touched a greater number of units composing the shape than did the right. These differences in the exploratory modes are thus robust and appear independently of experimental manipulation. Recall that our apparatus allows the extraction of information concerning the number of parts of the shapes that are touched by the subject's hand. However, strictly speaking, our apparatus provides no direct information with respect to hand movements. For example, we cannot tell which fingers haptically contact a given part of the stimulus. Notwithstanding, hypotheses concerning the functional significance of hand differences in the number of cubes touched can be drawn from the collected data. In particular, one can hypothesize that the left hand, with its greater span, uses a more global exploratory processing strategy than does the right. Alternatively, the right hand could explore the form in a more analytic fashion. However, for us, this kind of dichotomous explanation is too general to be heuristically useful. A more detailed analysis of hand movements is needed (see, for example, Lederman and Klatzky 1987) in order to better describe hand differences in exploratory procedures.

In summary, the current study validates the advantage of dichhaptic over monohaptic procedures for the detection of laterality effects. However, it has also revealed that the two hands rarely palpate simultaneously. We suggest that further studies on dichhaptic exploration should take into consideration this dimension of hand movements in order to reveal more reliable and homogeneous effects.

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