DSC-Vol. 58, Proceedings of the ASME Dynamics Systems
and Control Division
ASME 1996

58, 567 - 573

LEFT VERSUS RIGHT HAND DIFFERENCES IN EXPLORATORY STRATEGIES: FACTS AND RELEVANCE TO THE DEVELOPMENT OF HAPTIC DEVICES

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ABSTRACT

The literature provides conflicting results with regards to hand/hemisphere lateralization in haptic perception: while some papers report a left hand advantage for recognizing haptic forms, other studies indicate either a right hand advantage or no hand difference at all. Four experiments with right handed subjects will be presented, in which scanning strategies and performance were investigated when subjects touched nonsense forms by either the left or right hand. The research involved a novel apparatus and composite stimuli made of cubes whose junctions were not haptically discernible. During the inspection of the shape, the location and duration of any hand contact with the cubes comprising the stimulus were recorded, allowing thus an analysis of exploratory strategies. The first experiment implied the inspection of a target stimulus with either the left or right hand. Thereafter, subjects were requested to identify the drawing of the target stimulus displayed among different drawings. No hand differences were obtained in terms of scores. It was found, however, that in men the left hand touched the stimuli more globally than the right. In the second experiment, subjects were requested to inspect in simultaneity two forms with two hands (i.e., dichhaptic task), before recognizing the forms on the visual array. Here, the left hand outperformed the right hand. Moreover, as in the previous experiment, the left hand touched the shape more globally than the right. Results also demonstrated that only 20% of the total exploration time was devoted to a simultaneous inspection of the two forms. The two additional experiments focused on hand performance and exploratory strategies for recognizing the stimuli, instead of learning them. No hand differences were observed in strategy, whatever the mode of exploration (either dichhaptic or monohaptic). By contrast, recognition achieved by the left hand was better than that of the right hand, but this effect was restricted to dichhaptic recognition only. Overall, we conclude that this series of experiments demonstrates the reality of hand/hemispheric differences in the processing of haptic information by men. We argue, moreover, that these findings are of particular relevance for the development and use of haptic devices that are designed to display haptic information on body segments (e.g., tactile or force feedback devices). Firstly, they suggest a serious consideration of the laterality factor for stimulating subjects, in order to enhance pattern recognition. Secondly, they suggest that information presented to the left hand would be more easily processed if it was displayed globally, whereas information presented to the right hand would be more easily and efficiently processed when made available in a sequential manner. Finally, the results show a limited capacity to process two distinct sources of haptic information at the same time.

INTRODUCTION

The primate hand is one of the body segments best adapted for haptic perception, given its extreme mobility and a very high tactile acuity. The superiority of active touch compared to passive touch in haptic perception of objects (Gibson, 1962; Cronin, 1977; Heller, 1984) stresses the crucial role of exploratory activities in the way haptic information is processed. Indeed, the efficiency of haptic perception depends on both the nature of the stimulus and the nature of the scanning (e.g., Davidson, 1972). Lederman and Klatzky (1987), for instance, have described a series of stereotyped movements which are best adapted to perceive some specific properties of the object, like its texture, volume or shape. Thus, in order to perceive the shape of an object, the subject would adopt a 'contour following' strategy, which is the most effective strategy for shape perception, rather than, say, a 'static contact' strategy that is most adapted to perceive the temperature. At the developmental level, changes in exploratory activity are also coupled with improved perceptual skills (Piaget and Inheider, 1948; Abravanel, 1968; Ruff, 1984; Bushnell and Boudreau, 1991). Taken together, these data indicate that the choice and use of an appropriate exploratory activity is crucial for the effectiveness of haptic perception.

Distal hand movements are primarily controlled by the contralateral hemisphere in primates (Brinkman & Kuypers, 1973). Therefore, the perceptual abilities of the two hands must be affected by functional differences between the left and right cerebral hemispheres. At least in right-handed people, a left hand superiority is usually reported for recognizing nonsense stimuli by touch (see Verjat, 1988, 1989 for reviews). This asymmetry may be explained by a superiority of the right over the left hemisphere to process spatial information (Bradshaw and Nettleton, 1981; Heilige, 1993). The results obtained from brain damaged patients are congruent with the idea of superior abilities of the right hemisphere for haptic perception (e.g., Milner and Taylor, 1972; Nebes, 1971). Data on normal subjects are, however, less coherent. When only one stimulus is presented at a time (monohaptic testing), a left hand superiority is usually observed (Hatta, 1978; Cohen and Levy, 1986, 1988; Dodds, 1978; Flanery and Balling, 1979; Riege, Metter and Williams, 1980; Streitfeld, 1985). However, some studies report no hand difference in performance, (e.g., Yamamoto and Hatta, 1980; Webster and Thurber, 1978), and others show a right- instead of a left-hand superiority (e.g., Cranney and Ashton, 1982). Similarly, when the two hands explore simultaneously two objects (dichhaptic perception), most of the studies report a left hand advantage (e.g, Dawson, 1981; Gardner et al., 1977; Cohen and Levy, 1986, Nilsson and Geffen, 1987), while others show either a right hand advantage (Hannay and Smith, 1979, Labrèche et al., 1977), or no hand differences at all (Cranney and Ashton, 1980; O'Adams and Duda, 1986; Summers and Lederman, 1990). In sum, the literature usually demonstrates an asymmetry in favor of the left hand for recognizing nonsense haptic shapes, but this effect is not found systematically.

Interestingly enough, although the nature of exploratory activities has been found to be critical for the quality of haptic perception, very little is known at this point about the lateralization of haptic procedures. This lack of knowledge might be explained by the classical measurement of accuracy scores (or at best response times) as the unique way to infer hand/hemisphere differences. We would argue that this type of approach is of limited heuristic power for at least two reasons. First, consideration of accuracy scores provides information on the effectiveness of the process only, but gives no insight on the hemispheric modes of processing *per se*. Second, both hemispheres can solve the task by different ways, but with outcomes sometimes indistinguishable. For these two reasons, it seems important to supplement the analysis of performance with measures which allow one to evaluate more directly the processing modes of each hemisphere. In our recent studies, we tested the hypothesis that manual exploratory strategies can unveil the underlying cognitive operations and their lateralization. To test this hypothesis, we used a novel apparatus which has the capability to record the duration and location of digital contacts on haptic stimuli. These measures have then been used to infer manual exploratory strategies. We present below this novel approach in four complementary experiments involving either mono- or dichhaptic explorations of nonsense shapes. For a detailed description of the results reported below, the reader is referred to the following papers: Fagot, Lacreuse & Vauclair (1993), Fagot, Hopkins & Vauclair (1993), Fagot, Lacreuse & Vauclair (1994), and Lacreuse, Fagot Vauclair (1996). In conclusion, we will emphasize the importance the findings for the development of haptic interfaces.

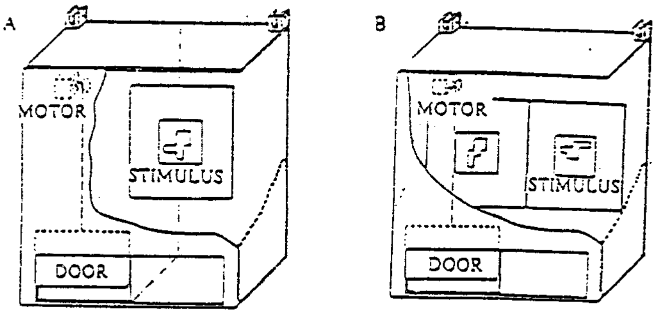

Figure 1. A front view of the testing apparatus; (A) for a monohaptic situation (B) for a dichhaptic situation.

METHODS

Subjects

Subjects were adults who reported themselves to use their right hand for writing, drawing, throwing a ball, teeth brushing, hammering and using a racket. We required that none of their close relatives were left-handed, because the presence of familial left handedness affects perceptual manual asymmetries (Varney and Benton, 1975).

Apparatus

The apparatus consists of an opaque 33 x 33 x 20 cm aluminium box (Figure 1). On the front of the box there are two side-by-side sliding doors independently operated by two motors. Raising the left or the right door provides a 7 x 14.5 cm access to the stimuli which are conceiled from view inside the box. The stimuli are on vertical pannels. Each pannel is fitted with four microswitches. Thus, pushing a stimulus backward activates the microswitches and provokes the end of the trial. The box is connected to an IBM-compatible PC computer via an A/D converter. On important feature of this apparatus is that, given the small size of the box, stimulus exploration must be performed by distal movements, rather than engaging more proximal elbow or shoulder movements. This feature is critical, because distal (but not proximal) movements are under the exclusive control of the opposite cerebral hemisphere (Brinkman & Kuypers, 1973). Moreover, this apparatus can easily be adapted to study a variety of different problems in the haptic domain. For example, if the difference between mono- and dichhaptic tasks is considered, either a single stimulus or two stimuli may be fixed inside the box. A more detailed technical description of the apparatus and its components can be found in Fagot, Arnaud, Chiambretto and Fayolle (1992).

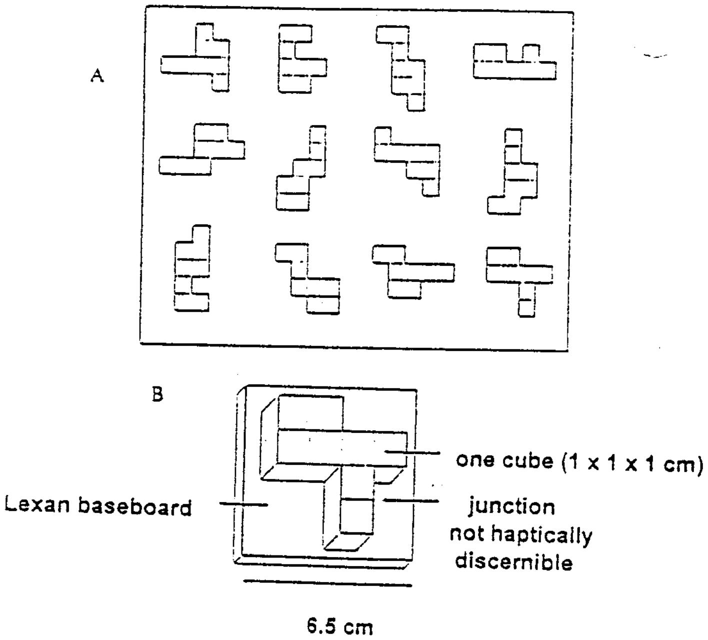

Figure 2. (A) Some of the stimuli used in the experiments; (B) detailed view of a stimulus.

Stimuli

Figure 2 illustrates the type of stimuli we used. They were three-dimensional nonsense forms which were designed according to the five following rules: first, they were all made of eight metallic cubes (1 x 1 x 1 cm) fixed side by side on a 6.5 x 6.5 cm lexan baseboard. Cubes were adjusted so precisely that their junctions were not haptically discernible. Second, stimuli were constructed with a maximum of five cubes in a row. Third, they were asymmetric with respect to the horizontal and vertical planes. Fourth, their contour comprised 10 angles and 10 sides. Fifth, mirror images or rotations of existing stimuli were systematically rejected. The maximal dimension of the stimuli was 5 cm.

During the experiment, each cube constituting the stimuli was positively polarized (+ 5V) and electrically insulated from the others. Providing that the subject was grounded, any hand contact with a cube shifted its voltage from +5 to 0 V. These electric variations were recorded on-line by the computer and later used to infer haptic strategies.

Procedure

A common experimental design was adopted for all four experiments reported here. During a trial, the subject was seated at a table, facing the apparatus. A grounded home plate (30 x 20 cm) was laid on the table in front of the subject. At the beginning of each trial, the subject put his/her two hands on the plate and waited for a warning tone and the opening of either one (monohaptic situation) or two doors (dichhaptic situation). When the test involved a monohaptic exploration, the stimulus was explored by the hand ipsilateral to the opened door. By contrast, when a dichhaptic exploration was requested, the two hands were introduced inside the box in order to explore the two stimuli simultaneously, one stimulus in each hand. Some tests involved an initial exploration of a sample stimulus followed by a recognition phase. In this case, the first exploration was limited to 10 seconds and the second one (recognition phase) was aborted when the subject gave his/her response and pushed one stimulus. At the end of a trial, the subject placed his/her hands on the grounded-plate again, waiting for the next trial to begin.

Dependent Variables

Stimuli were explored by distal movements of the fingers. We chose the mean number of cubes that were simultaneously touched during the trials as the primary dependent variable. This variable was used because it was expected to reflect the mode of stimulus processing in a direct way. It should, for instance, allow for a distinction of a holistic from a sequential investigation of the shapes. Accuracy scores were also recorded.

The first two experiments reported below concerned manual strategies during the initial exploration of sample stimuli, either in a monohaptic or in a dichhaptic situation. The next two experiments also involved monohaptic and dichhaptic explorations, but focused on the recognition phase, rather than on the initial exploration.

EXPERIMENT 1: MONOHAPTIC TACTUAL-VISUAL SITUATION

The aim of this first experiment was to examine manual exploratory strategies when subjects learned nonsense shapes by touch. Twenty four adults (12 men and 12 women) had to explore a single stimulus with one or the other hand in order to later recognize it among 3 drawings presented in a visual array. The response was to point at the drawing which matched the tactile stimulus.

Data analyses were conducted independently for the two sexes, in order to control for gender differences in hand size. In 7.4 percent of the trials, the computer failed to record hand contact on each cube. These trials were rejected from the analysis, because the lack of hand contact detection could be due to improperly connected cubes, rather than to an incomplete exploration of the stimulus. Overall, there were no hand difference in scores for both men (LH=77.6% correct; RH=80.93%) and women (LH=72.74%; RH=71.74%). We noted in men, however, that the left hand simultaneously touched a greater number of cubes (M=5.38) than the right hand (M=5.06, $p<.001$). In women, this effect was marginally significant (LH=4.13, RH=3.97; $p=.07$). Consistent with this finding, McGlone (1980) reported a series of studies showing weaker hemispheric lateralization in women than in men.

We also considered the number of cubes simulatenously contacted during the very early contact of the hand with the shape, namely before active exploration of the object's contour. As previously found, the left hand simultaneously touched a greater number of cubes than the right hand, and this effect was significant for both sexes (men: LH=3.13; RH=2.26, $p<.01$; women: LH=1.45; RH= 1.28, $p<.05$).

In brief, this experiment validated our approach by showing that the asymmetries in manual exploratory strategies are not necessarily expressed at the performance level. As predicted, the results suggest that manual exploratory strategies are more sensitive to laterality effects than accuracy. Assuming that the number of simultaneously touched cubes reflects the quantity of information processed in parallel, we conclude that the right-hand/left hemisphere system processes the haptic information in a more sequential manner than the left-hand/right hemisphere system.

Some authors have suggested that monohaptic situations are inadequate to reveal manual asymmetries, and proposed instead the use of dichhaptic tasks (e.g, Witelson, 1974, 1976). The second experiment thus focussed on the analysis of accuracy scores and exploratory strategies in a dichhaptic task.

EXPERIMENT 2: DICHHAPTIC TACTUAL-VISUAL SITUATION

The aim of this second experiment was twofold. First, we wanted to know if asymmetries would be obtained in accuracy scores in a dichhaptic task. Second, we wanted to verify the assumption that the two hands would also differ in their exploratory strategies when a dichhaptic exploration is requested.

Only men (n=14) were tested, because the previous study showed greater asymmetries in men than in women. In a first phase of each trial, the subjects explored two tactile stimuli simultaneously (dichhaptic exploration). Then, they were requested to indicate by pointing if they recognized the one of the two tactile stimuli that was on a visual array comprising three drawings.

As can be seen in Figure 3, results indicated that the stimuli touched by the left hand (M=81.5%) were more often recognized than those touched by the right hand (M=72.6%, p<.05). Moreover, consistent with the results of t6/22/96he previous experiment, the left hand also touched more cubes in parallel (M=4.6) than the right hand (M=4.4; p<.05). Overall, these data suggest that the dichhaptic mode of exploration favors the emergence of manual asymmetries at the performance level.

Witelson (1976) has proposed that the dichhaptic situation, in which the two hands are active simultaneously, creates a competition between homologous areas in the left and right hemispheres, thus leading to enhanced lateral differences. To test this hypothesis, we verified that the two hands really explored the two objects simultaneously. The results showed that the subject effectively touched the two objects at the same time, as requested by the experimenter. However, they actively explored the objects in a sequential way. In fact, during 80% of the total exploration time, only one hand was moving at a time, and the other remained motionless. This finding shows that the two hands do not work in parallel. One feature of the dichhaptic situation, compared to the monohaptic condition, is to increase the complexity of the task because the subject has to deal with two objects, instead of one. We hypothesized that this constraint enhances the memory load of the task, thus favoring the expression of hemispheric differences.

Turning now to manual exploratory strategies, the results of this study replicated those of the previous one, in that more cubes were touched on average by the left than the right hand. Note that this effect is small in amplitude. This effect seems, however, to be strongly reliable, because it occurred in both the mono- and dichhaptic testings.

In normal conditions, the visual modality usually dominates the haptic one (see McGurk and Power, 1980; Hatwell, 1986). We propose that our tactual-visual procedures (experiments 1 and 2) have favored a visual encoding of the tactual information. To circumvent this problem, we ran an additional experiment in which the learning and recognition phases only involved the tactual modality.

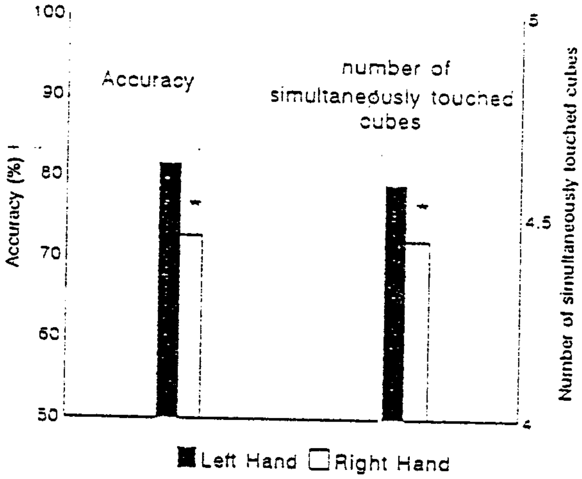

Figure 3. Accuracy (in percentage) and number c simultaneously touched cubes as a function of th exploring hand (left or right) in the dichhaptic tactua visual experiment (Experiment 2).

EXPERIMENT 3: RECOGNITION PHASE IN A DICHHAPTIC TACTUAL-TACTUAL SITUATION

Nine men were tested in Experiment 3. They were asked to recognize by touch some previously memorized nonsense haptic forms. In the first phase of the experiment, the subjects learned four target stimuli equally presented (with no time constraint) to the left or right hand by using a monohaptic procedure. In the second phase, one of the four target stimuli and a novel form were simultaneously presented to both hands. The task was to inspect the two forms, and then, to push the target stimulus.

Results showed that the left hand (M=80.6% correct) was better than the right (M=72.2%; p=.05) to recognize the targets. Again, this finding emphasizes the usefulness of the dichhaptic procedure for revealing manual asymmetries. Concerning manual exploratory strategies, we did not find any significant difference between the left (M=5.05) and right hand (M=5.1). This lack of significant difference does not derive from the use of a dichhapic procedure, because the same procedure showed lateralization in the previous experiment. Rather, the main difference between this experiment and the previous one is that we analyzed strategies in the recognition phase, rather than during the initial encoding of the shape. From this observation, we conclude that asymmetries in manual strategies are more likely to be expressed during the initial encoding of the stimulus, when the subject has to memorize it, than during its recognition. To test this hypothesis, we ran a fourth experiment in which strategies were analyzed during both the learning and recognition phase.

EXPERIMENT 4: LEARNING AND RECOGNITION PHASES IN A MONOHAPTIC TACTUAL-TACTUAL SITUATION

This fourth experiment comprised a learning phase followed by a recognition phase. In the learning phase, the subjects (i.e., 14 men) had to monohaptically investigate a target stimulus. Then, after a four seconds delay, another stimulus was presented to the same or to the other hand. The task was to indicate, as fast as possible, whether the second object was identical to or different from the target stimulus. For half of the trials, the comparison stimulus was identical to the target. For the other half, it was different. The response was to push the stimulus once or twice depending on the type of judgment to be made (identical or different).

The performance of the two hands were similar, ($LH=70.3\%$ correct; $RH=70.1\%$, $P>.1$). However, when only one hand is used to explore and to recognize the stimulus, the performance was better if the stimuli were identical ($M=70.66\%$) than if they were different ($M=60.1$, $P<.05$). This effect appeared regardless of the hand used.

Concerning manual strategies, we found that the left hand explores more cubes simultaneously ($M=4.5$) than the right hand ($M=4.27$; $p<.001$). Moreover, this asymmetry appeared for the learning phase only.

To sum up, data from this research are congruent with the hypothesis that the monohaptic situation is less effective than the dichhaptic in revealing lateralization. Moreover, the findings demonstrate that hand differences in exploratory strategies occur during the learning phase only, whatever the testing situation (either mono- or dichhaptic).

Experiment	Exploratory mode	Procedure	Phase	Accuracy (%)	Number of simultaneously touched cubes
1	Monohaptic	T-V	Learning	ns.	LH > RH ($p<.001$)
2	Dichhaptic	T-V	Learning	LH > RH ($p<.05$)	LH > RH ($p<.05$)
3	Dichhaptic	T-T	Recognition	LH > RH ($p=.05$)	ns.
4	Monohaptic	T-T	Learning and Recognition	ns.	LH > RH ($p<.001$) ns.

Table 1. Summary of the main findings with regards to accuracy score and strategy (i.e, number of cubes simultaneously touched). T-V: Tactual-Visual: T-T: Tactual-Tactual; LH : Left Hand; RH: Right Hand;

GENERAL DISCUSSION

In this paper, we have presented a novel approach to study hemispheric lateralization in haptic perception in four experiments with humans. The lateralization of haptic perception has been studied not only from the analysis of hands performance, the measure classically used in the literature, but also from an investigation of manual exploratory strategies.

The facts.

The findings of the four experiments may be summarized as follows (see also Table 1). First, the better performance of the left hand was found in Experiments 2 and 3 only, that is for the only two experiments implying a dichhaptic situation. This result suggests that the simultaneous exploration of both hands favors the emergence of hand performance asymmetries. Rather than a competitive effect between the hemispheres (see Witelson, 1976), we suggest that the cognitive constraints involved in this mode of exploration (attention sharing, memory load) are determinant for the emergence of hand performance asymmetries. Second, small but relialable differences between the left and right hands were found in strategies, as inferred by the number of cubes simultaneously touched. Lateral effects in strategies indicated that the left hand explores the stimulus in a more global way (i.e., touches more cubes simultaneously) than the right. Differences in manual strategies, however, emerged during the initial encoding of the target stimulus only (learning phase), but not during the recognition phase. To sum up, lateralization was observed in both the learning phase (in terms of score and strategy in the dichhaptic tasks, or in terms of strategies in the monohaptic task), and in the recognition phase (in terms of score in the dichhaptic task). In should be noted, however, that the above results derived from men only (Experiments 2-3), leaving uncertain if similar findings would be found with women.

Implications for the development of haptic devices

We mentioned above that the literature provides inconsistent findings with regard to the existence of manual asymmetry in the processing of haptic information. Our research indicates the reality and strength of lateral differences, even if they do not always correspond to differences in performance between the two hands. In several respects, we believe that this finding is of particular relevance for the development of haptic devices, namely for devices displaying haptic information (e.g., vibrotactile stimulation). First, they suggest that haptic information is processed more efficiently if they are perceived by the left hand (right hemisphere), than by the right hand, at least in dichhaptic explorations (Experiments 2 and 3). Whether this finding is restricted to hand perception or may be found with other left-sided body segments remains an empirical question. Nevertheless, it appears that stimulations applied by haptic devices, such as force or tactile feedback virtual reality devices, are more likely to be processed efficiently if it is perceived by the left hand, at least for pattern identification (see also, Heller et al., 1990). This conclusion may not be restricted to perception of nonsense shapes, however, because a left hand advantage is sometimes reported with some significant materials such as Braille symbols (e.g., Hermelin &

O'Connor, 1971) or digits (Heller et al., 1990). Secondly, our study shows hemispheric differences in the way haptic information is processed, independently of asymmetries in performance, because the right hemisphere was found to investigate the shapes in a more global way than the left. Again, this finding may be important to consider when haptic devices are built, in order to optimize the way haptic stimulation is made available to the left and right hands or body segments. Finally, the analysis of exploratory strategies revealed a limited capacity of the subjects to process two distinct sources of information at the same time. This limitation is made obvious in the dichhaptic task, in which the subjects touched the two objects in simultaneity, but investigated them actively in a sequential way. At this point in the research, the generalization of the findings presented here remains an empirical question. In particular, if remains to be demonstrated if the above effects would be observed when the two hands inspect a single object, or even, if the object is more readily accessible to the exploration, for instance by a lifting or grasping mode. Nevetheless, this line or research is promising, and calls for a consideration of hand/hemispheric asymmetries in both fundamental and applied research on haptic perception.

REFERENCES

Abravanel, E. 1968. The development of intersensory patterning with regards to selected spatial dimensions. *Monographs of the Society for Research in Child Development*, serial n°118, vol. 33, 1-52.

Bradshaw, J.L. & Nettleton, N.C. 1981. The nature of hemispheric specialization in man. *The Behavioral and Brain Sciences*, 4, 51-63.

Brinkman, C. & Kuypers, H.G.J.M. 1973. Cerebral control of contralateral and ipsilateral arm, hand and finger movements in the split-brain rhesus monkey. *Brain*, 96, 653-674.

Bushnell, E.W. & Boudreau, J.P. 1991. Haptic perception during infancy, 139-167. In Morton, A. H. & Schiff, W. (Eds.), *The psychology of touch*, Hillsdale, NJ: Lawrence Erlbaum.

Cohen, H., & Levy, J. 1986. Cerebral and sex differences in the categorization of haptic information. *Cortex*, 22, 253-259.

Cohen, H. & Levy, J. 1988. Hemispheric specialization for tactile perception opposed by controlateral noise. *Cortex*, 24, 425-431.

Cranney, J., & Ashton, R. 1980. Witelson's dichhaptic task as a measure of hemispheric asymmetry in deaf and hearing populations. *Neuropsychologia*, 18, 95-98.

Cranney, J., & Ashton, R. 1982. Tactile spatial ability : Lateralized performance of deaf and hearing age groups. *Journal of Experimental Child Psychology*, 34, 123-134.

Cronin, V. 1977. Active and passive touch at four age levels. *Developmental Psychology*, 13, 253-256.

Davidson, P.W. 1972. The role of exploratory activity in haptic perception: Some issues, data, and hypotheses. *American Fundation for the Blind Research Bulletin*, 24, 21-27.

Dawson, G.D. 1981. Sex differences in dichaptic processing. *Perceptual and Motor Skills*, 53, 935-944.

Dodds, A.G. 1978. Hemispheric differences in tactuo-spatial processing. *Neuropsychologia*, 16, 247-254.

Fagot, J., Arnaud, B., Chiambretto, M. & Fayolle, R. 1992. Lateralization in haptic processing: An apparatus to analyse manual strategies. *Behavior Research Methods, Instruments and Computers*, 24, 54-59.

Fagot, J., Hopkins, W.D. & Vauclair, J. 1993. Hand movements and hemispheric specialization in dichhaptic explorations. *Perception*, 22, 847-853.

Fagot, J., Lacreuse, A. & Vauclair, J. 1993. Haptic discrimination of nonsense shapes: Exploratory strategies but not accuracy reveal laterality effects. *Brain and Cognition*, 21, 212-225.

Fagot, J., Lacreuse, A. & Vauclair, J. 1994. Hand movement profiles in a tactual-tactual matching task: Effects of spatial factors and laterality, *Perception & Psychophysics*, 56, 347-355.

Flanery, R.C. & Balling, J.D. 1979. Developmental changes in hemispheric specialization for tactile spatial ability. *Developmental Psychology*, 15, 364-372.

Gardner, E.B., English, A.G., Flannery, B.M., Hartnett, M.B., MacCormick, J.K. & Wilhelmy, B.B. 1977. Shape-recognition accuracy and response latency in a bilateral tactile task. *Neuropsychologia*, 15, 607-616.

Gibson, J.J. 1962. Observations on active touch. *Psychological Review*, 69, 477-491.

Hannay, H.J. & Smith, A.C. 1979. Dichhaptic perception of forms by normal adults. *Perceptual and Motor Skills*, 49, 991-1000.

Hatta, T. 1978. The fonctional asymmetry of tactile pattern learning in normal subjects. *Neuropsychologia*, 21, 83-89.

Hatwell, Y. 1986. *Toucher l'espace. la main et la perception tactile de l'espace*, Lille: Presses Universitaire de Lille.

Heller, M.A. 1984. Active and passive touch: The influence of exploration time on form recognition. *Journal of General Psychology*, 110, 243-249.

Heller, M., Rogers, G.J. & Perry, C.L. 1990. Tactile pattern recognition with the optacon: Superior performance with active touch and the left hand. *Neuropsychologia*, 28, 1003-1006.

Hellige, J.B. 1993. *Hemispheric asymmetry. What's right and what's left.* London: Harvard University Press.

Hermelin, B. & O'Connor, N. 1971. Spatial coding in normal, autistic and blind children. *Perceptual and Motor Skills*, 33, 127-132.

Labrèche, T.M., Manning, A.A., Goble, W. & Markman, R. 1977. Hemispheric specialization for linguistic and nonlinguistic tactual perception in a congenitally deaf population. *Cortex*, 13, 184-194.

Lacreuse, A., Fagot, J. & Vauclair, J. (1996). Latéralisation hémisphérique et stratégies d'exploration dans des tâches de perception tactilo-kinesthésique. *L'Année Psychologique*, 96, 131-145.

Lederman, S.J. & Klatzky, R. 1987. Hand movements: A window into haptic object recognition. *Cognitive Psychology*, 19, 342-368.

McGlone, J. 1980. Sex differences in human brain asymmetry: A critical survey. *The Behavioral and Brain Sciences*, 3, 215-263.

McGurk, H. & Power, R.P. 1980. Intermodal coordination in young children: Vision and touch. *Developmental Psychology*, 16, 679-680.

Milner, B. & Taylor, L. 1972. Right-hemisphere superiority in tactile pattern-recognition after cerebral commissurotomy: Evidence for nonverbal memory. *Neuropsychologia*, 10, 1-15.

Nebes, R.D. 1971. Superiority of the minor hemisphere in commissurotomized man for the perception of part-whole relations. *Cortex*, 7, 333-349.

Nilsson, J. & Geffen, G. 1987. Perception of similarity and laterality effects in tactile shape recognition. *Cortex*, 23, 599-614.

O'Adams, J.O. & Duda, P.D. 1986. Laterality of cross-modal spatial processing. *Cortex*, 22, 539-552.

Piaget, J. & Inhelder, B. 1948. *La représentation de l'espace chez l'enfant.* Paris: Presses Universitaires de France.

Riege, W.H., Metter, E.J. & Williams, M.V. 1980. Age and hemispheric asymmetry in nonverbal tactual memory. *Neuropsychologia*, 18, 707-710.

Ruff, H.A. 1984. Infants' manipulative exploration of objects: Effects of age and object characteristics. *Developmental Psychology*, 20, 9-20.

Streitfeld, B. 1985. Hemispheric advantages and shifts of laterality differences in visual and tactual modalities. *International Journal of Neuroscience*, 25, 245-254.

Summers, D.C. & Lederman, S. 1990. Perceptual asymmetries in the somatosensory system: A dichhaptic experiment and critical review of the literature from 1929 to 1986. *Cortex*, 26, 201-226.

Varney, N.R. & Benton, A.L. 1975. Tactile perception of direction in relation to handedness and familial handedness. *Neuropsychologia*, 13, 449-454.

Verjat, I. 1988. La dissymétrie fonctionnelle cérébrale dans la modalité tactilo-kinesthésique manuelle. *L'Année Psychologique*, 88, 83-109.

Verjat, I. 1989. A propos de l'exploration dichhaptique. *L'Année Psychologique*, 89, 277-289.

Webster, W.H. & Thurber, A.D. 1978. Problem-solving strategies and manifest brain asymmetry. *Cortex*, 14, 474-484.

Witelson, S.F. 1974. Hemispheric specialization for linguistic and nonlinguistic tactual perception using a dichotomous stimulation technique. *Cortex*, 10, 3-17.

Witelson, S.F. 1976. Sex and the single hemisphere: Specialization of the right hemisphere for spatial processing. *Science*, 193, 425-427.

Yamamoto, M. & Hatta, T. 1980. Hemispheric asymmetries in a tactile thought task for normal subjects. *Perceptual and Motor Skills*, 50, 469-471.

ACKNOWLEDGEMENTS

This article was supported by a postdoctoral fellowship from the Fondation pour la Recherche Médicale to Agnès Lacreuse. We are grateful to Amy Galloway for her help with the manuscript.