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Haptic Discrimination of Nonsense Shapes: Hand Exploratory Strategies but Not Accuracy Reveal Laterality Effects

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Studies on haptic processing show inconsistent results concerning sex and hand differences. We present a novel approach in which manual exploratory strategies were examined. Twenty-four right-handed adults of both sexes had to monohaptically explore unseen meaningless stimuli and then to recognize their visually presented outline drawings among drawings of different stimuli. Tactual stimuli were composed of eight smoothly joined cubes whose junctions were not haptically discernible. The computer recorded number and duration of hand contacts on each cube. Analyses included the accuracy of the recognition phase, the number and duration of exhaustive explorations of the stimulus, and the number of cubes simultaneously touched. Neither hand nor sex differences were found for the accuracy measurement. The number and duration of exhaustive explorations also provide no evidence of hand differences. However, the left hand touched simultaneously more cubes than the right and this asymmetry was more pronounced in males than in females. Such an asymmetry was apparent in the very first contact of the hand with the shape. It is suggested that exploratory strategies may be more sensitive measures in revealing hand lateralization than the accuracy measurement.

INTRODUCTION

Hemispheric specialization for haptic processing has been documented in a large number of studies (for a review see Summers & Lederman, 1990). In general, when meaningless stimuli were used, perceptual asymmetries were usually found in favor of the left hand for right-handed persons (e.g., Benton, Harvey, & Varney, 1973; Dodds, 1978; Riege, Metter, & Williams, 1980; Verjat, 1988; Weener & Van Blerkom, 1982), which could reflect a better treatment of spatial information by the right

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hemisphere. Moreover, sex differences have often been reported with males being either more strongly lateralized (Flanery & Balling, 1979, for the adult subgroup) or more accurate than females (e.g., Dawson, 1981). However, these hand and sex effects were not systematically found and several studies provided conflicting results with regard to hand differences (e.g., Hannay & Smith, 1979; Cranney & Ashton, 1980; Yandell & Elias, 1983) as well as with regard to sex differences (e.g., Denes & Spinaci, 1981; Weener & Van Blerkom, 1982).

We suggest that discrepancies in results could be at least partially explained by the choice of the dependent variables (DVs). Clearly, accuracy measurement has been chosen most of the times as DV. It seems that this measure of performance raises two major problems. First, accuracy as a global measure of the output of an information processing provides little insight about the manner in which information is treated. It is in fact this very processing (e.g., global vs. analytic treatment) that researchers attempt to tap through the evaluation of the performance. Second, the use of recognition accuracy as a DV assumes that different kinds of information processing should produce differences in performance. However, it is possible that the same outcome results from different cognitive treatments. For example, when enough time for exploring a shape is given, both a sequential and a global exploration of the form could lead to the same accurate recognition. There are probably also situations in which both kinds of processing do not lead to successful recognition.

In a haptic discrimination task, the hand has interdependent perceptual and motor functions. On the perceptual side, the hand has to sense the form or other critical dimensions of the object. On the motor side, it has to displace the digital sensors in order to achieve the perception. Thus, perceptual processes as well as cognitive treatments are, at least partially, expressed by the finger movements (Lederman & Klatzky, 1987), especially when attention is focused toward that perception. The present study takes advantage of these characteristics of haptic discrimination. To paraphrase Lederman and Klatzky (1987), hand movements will serve as "windows" for learning about the haptic system. That study will examine exploratory schemes as they are expressed by the movements of the hand on the object. An ad hoc apparatus was designed and spatial and temporal indices of exploratory strategies were defined to that purpose. DVs will be indices of exploratory strategies in addition to the common measurement of accuracy.

METHODS

Subjects

Subjects were 24 adults (12 males and 12 females), ages 19–29 years (mean = 23.5, SD = 2.4). They reported being right-handed in a six-item laterality questionnaire (writing,

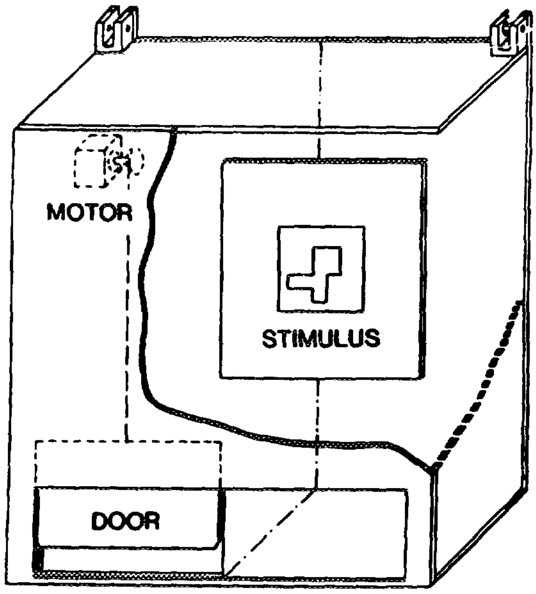

FIG. 1. Front view of the apparatus showing the door mechanism with the motor and the stimulus display.

drawing, ball throwing, teeth brushing, hammering, and racket using). Moreover, only subjects with no sinistral parent were retained. They were paid for participating in the experiment.

Apparatus and Stimuli

The apparatus used in this study is described in detail by Fagot, Arnaud, Chiambretto, & Fayolle (1992). Briefly, as depicted in Fig. 1, it consisted of an aluminum opaque box-shaped apparatus (33 × 33 × 20 cm) containing a single stimulus to be touched. The box was equipped on its front with two side-by-side vertically sliding doors. A door opening provided a 7 × 14.5-cm access to the stimulus. Each door was operated by a motor. The vertical rear of the box was fitted with a 16.4 × 15.4-cm panel. This panel had a central aperture (6.6 × 6.6 cm) inside which the stimulus was fixed vertically 10 cm above the base of the box and 5 cm behind its front. The apparatus was connected to an IBM-compatible PC computer via an Analogic/Digital converter.

Stimuli were made of several metallic cubes (1 × 1 × 1-cm each) fixed side by side on a 6.5 × 6.5-cm lexan baseboard (see Fig. 2). Cubes were so precisely adjusted that their junctions were not haptically discernible. A plastic layer was inserted between them in such a way that they were electrically insulated. Each cube was positively polarized (+5 V). Providing that the subject was grounded, any hand contact with a unit shifted its voltage from +5 to 0 V. Such electric variations were recorded by the computer and later used to analyze haptic strategies (see Fagot et al., 1992, for details about the electronic components and software).

The judged complexity of geometric forms may depend on the number of angles in their contours and on their symmetry (in the tactual modality: Attneave, 1957; in the visual modality: Simon, 1972; Quinlan, 1991). In order to homogenize stimulus complexity, these

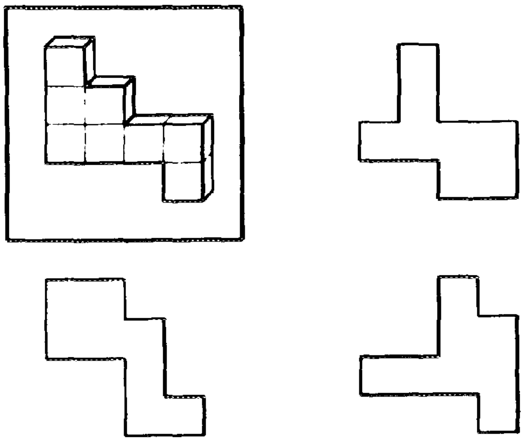

FIG. 2. (Top left) Drawing of a tactile stimulus representing the lexan panel and the eight cubes. (Other drawings) Outline of three other stimuli used in the experiment.

two variables were considered for constructing nonsense shapes. Twelve different three-dimensional nonsense stimuli were built. These forms differed with respect to two dimensions only. A sample of the stimuli employed is provided in Fig. 2. As exemplified in this figure, stimuli were designed according to the five following rules. First, they were all made of eight cubes. 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 contours comprised 10 angles and 10 sides. Fifth, mirror images or rotations of existing stimuli were systematically rejected.

Procedure

The experiment was run in a quiet room. As shown in Fig. 3, the subject was sitting at a table and was facing the box apparatus. A grounded home plate (30 × 20 cm) was also laid on the table. A vertical opaque board (110 × 65 cm) prevented subjects from viewing the experimenter as well as components of the system other than the front of the box-shaped apparatus.

Trials began with a warning tone after which the subject laid his two hands on the home panel. Three seconds after the bip, one door (either the left or the right) was opened. Depending on which door opened, the subject inserted his left or right hand inside the box in order to explore the shape. The other hand remained on the home panel. The small size of the shape imposed a distal exploration by the finger tips. Distal hand movements are necessary to involve the hemisphere contralateral to the hand used (e.g., Brinkman & Kuypers, 1973). The subject was allowed 10 sec to explore the form. Timing started when the hand touched one of the cubes composing the stimulus. At the end of the 10-sec exploration period, a tone was delivered and, 1 sec later, the door was closed. At that time, the experimenter presented a paperboard to the subject with the outline drawings of three different shapes. These shapes had the same scale as the haptic stimulus. The visual shapes were made following the five rules used for building the tactile stimulus. Drawings were displayed above the top of the carton screen, on the median plane of the subject. One drawing represented the previously monohaptically inspected stimulus. The two others, which belonged to a set of 24 drawings, represented stimuli which differed from the tactile

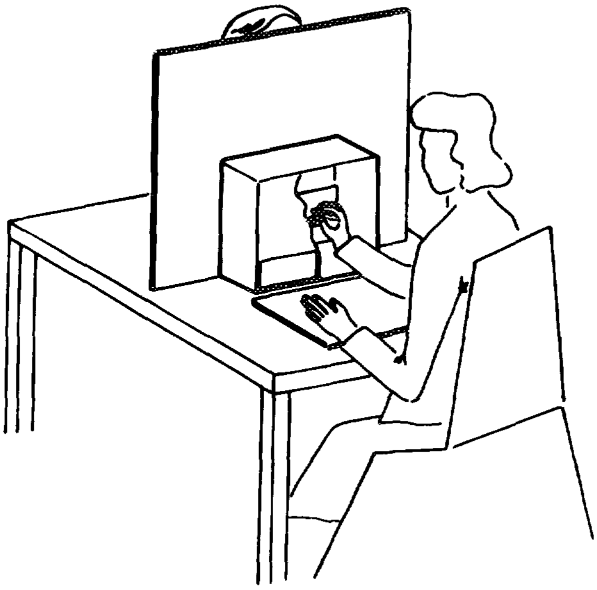

FIG. 3. Illustration of the experimental setup showing a subject touching the stimulus with the right hand while the left hand is resting on the grounded home plate.

stimulus set. The subject pointed with a designated hand to the drawing he/she thought corresponded to the stimulus. No time restriction or feedback for subject's response was given.

Subjects performed two blocks of 24 experimental trials for a total of 48 trials per individual and 1152 trials for the group. The intertrial interval was 80–100 sec and a break of 10 min separated the two experimental blocks. Each stimulus was used four times during the experiment and was explored once with each hand in each block. Forms were always presented in the same orientation. The order of stimuli presentation was identical for each block of trials, and, within a block, all 12 stimuli were presented once in a fixed order prior to the repetition of the set of 12 stimuli. Pointing was made with a given hand during the first block, whereas the other hand was used to point during the next block. Twelve subjects, six males and six females, began pointing with the left hand. The remaining subjects began with the right hand. Before testing, the subject was instructed that his/her task would be to touch a form and then to recognize their outline drawings on the basis of the two relevant dimensions. The hand used to point was also indicated. The subject was allowed two practice trials with a stimulus that was different from the 12 experimental forms.

The design of the apparatus and the construction of the stimulus made possible a description of the exploratory strategy. In practice, the subjects usually touched several cubes simultaneously. This behavior was translated by the computer as a sequence of recordings indicating (1) the identification of the touched units and (2) the onset of the contact. Table 1 illustrates a recording for one trial. In this example, the subject has touched only one unit (number 6) at the exploration onset (time 0). Seventy-four milliseconds later, his/her hand always touched unit 6 along with three additional cubes (numbers 3, 5, and 7). It took 498 msec for the subject to perform a first investigation of the eight units composing the shape and thus to complete a first exhaustive exploration of the stimulus.

TABLE 1
Example of a Computer Output for One Trial

Time	Unit identity								Number of units
0						6			1
74			3		5	6	7		4
146			3		5		7		3
194			3		5		7	8	4
244			3	4	5			8	4
346			3	4	5				3
394			3		5				2
498	1	2	3		5	6	7		6
(Intervening events deleted to save space)									
8606	1	2	3		5		7	8	6
9092	1	2	3	4	5	6	7		7
9134		2				6			2

On the basis of these data, five DVs were derived. The first one was the global touch time, that being the total time that any part of the stimulus was contacted. The second variable was the number of exhaustive explorations. As exemplified above, an exhaustive exploration was counted when all eight cubes have been touched at least one time. All eight cubes must be retouched to count an additional exhaustive exploration. The third DV was the duration of exhaustive explorations, namely the average time needed to perform an exhaustive exploration as defined above. The fourth DV was the number of cubes simultaneously touched (see example provided on Table 1), that is the average number of cubes that were simultaneously touched during the 10-sec period. Finally, accuracy which corresponded to the outcome of the recognition phase (success or failure), was recorded. Accuracy was noted manually by the experimenter.

Data Analysis

Accuracy data were analyzed using a four-factor 2 × 2 × 2 × 2 analysis of variance (ANOVA) with gender (male or female) as the unique between-subject factor and block (first, second), pointing hand (left or right), and touching hand (left or right) as the three within-subject factors. Exploratory strategy data were performed independently for males and females because sex comparisons with regard to hand exploratory strategies could be affected by possible sexual dimorphism, for example in hand size. For each sex, we computed a 2 × 2 ANOVA with the block and touching hand variables used as within-subject factors.

RESULTS

Among the 1152 trials performed by the subjects, there were 85 cases (7.4%, mean per subject = 3.5) in which the computer failed to record any contact on all units. These trials were rejected for the analyses because they could be due to improperly connected cubes. For the 1067 remaining trials, Table 2 shows the basic descriptive statistics (means and SDs) for each DV and sex × hand categories.

TABLE 2
Means (in Bold) and Standard Deviations (in Parentheses) for Each Sex by Touching Hand Category for the Accuracy (Percentage Correct), the Global Touch Time (Seconds), the Number of Exhaustive Explorations, the Duration of Exhaustive Explorations (Seconds), and the Number of Cubes Simultaneously Touched

	Males		Females	
	Left	Right	Left	Right
Accuracy	**77.66**	**80.93**	**72.74**	**71.44**
	(13.0)	(10.98)	(11.46)	(12.58)
Global touch time	**9.84**	**9.80**	**9.70**	**9.84**
	(.082)	(.179)	(.287)	(.149)
Number of explorations	**4.29**	**4.23**	**3.60**	**3.44**
	(1.49)	(1.50)	(1.19)	(1.30)
Duration of explorations	**2.03**	**2.21**	**2.95**	**3.20**
	(.84)	(1.15)	(1.19)	(1.35)
Number of touched cubes	**5.38**	**5.06**	**4.13**	**3.97**
	(.97)	(.90)	(.71)	(.72)

Accuracy of Recognition

On average, 79.29% (SD = 11.89) of the trials for the males and 72.09% (SD = 11.79) of the trials for females led to a correct identification on the visual board of the haptically explored form. The block × pointing hand × touching hand ANOVA did not reveal any statistically significant main effect. The only significant effect was a pointing X touching hand interaction ($F(1, 22) = 11.98, p < .01$). There was greater accuracy when the same hand was used to touch the shape and to point toward the visual array than when the pointing hand was not the touching hand. This interaction is illustrated in Fig. 4.

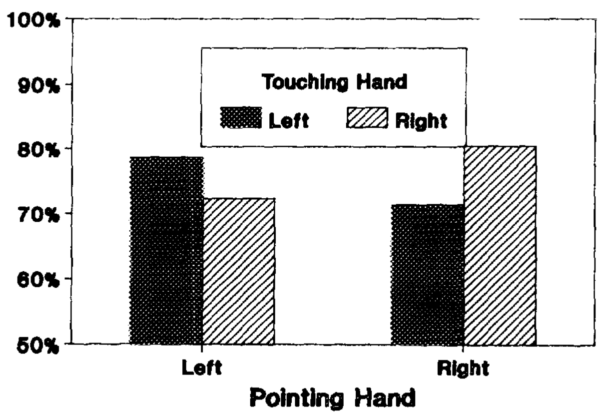

FIG. 4. Interaction between the touching and pointing hands for the percentage of accurate responses.

Global Touch Time

Subjects were allowed 10 sec to explore the stimulus. It appears that they used that time span since both males (mean = 9.82, SD = .140) and females (mean = 9.77, SD = .238) approached the 10-sec limit on average. Given that these means are very close to the maximum value, it is not appropriate to further analyze them because data are constrained by a ceiling effect.

Number and Duration of Exhaustive Explorations

The stimulus was explored on average 4.26 times (SD = 1.48) by the males and 3.52 times (SD = 1.24) by the females. The block × touching hand ANOVA revealed no significant main effect or interaction effect whichever group was considered (male or female).

With respect to the duration of exhaustive explorations, they lasted 2.12 sec (SD = .99) on average for the males and 3.08 sec (SD = 1.27) on average for the females. ANOVAs performed on data from each subgroup of sex indicated no significant main touching hand or block effect as well as no significant block × touching hand interaction.

Number of Cubes Simultaneously Touched

Regarding data from males, the ANOVA performed on the number of cubes simultaneously touched indicated significant effects of the touching hand and block. The block × touching hand interaction was not significant. The left hand touched a greater number of cubes than the right hand ($F(1, 11) = 29.4$, $p < .001$). The number of cubes touched was found to be greater during the first block (mean = 5.37, SD = .9) than during the second block of trials (mean = 5.07, SD = .97, $F(1, 11) = 6.012$, $p < .05$). A similar analysis performed with the females' data revealed a marginal hand effect which corresponded to a greater number of cubes touched by the left hand than by the right hand ($F(1, 11) = 3.85$, $p = .075$). Neither block nor block × hand interactions were significant.

We also looked at the first hand contact with the shape, namely the number of units touched when the hand encountered the stimulus. Block × touching hand ANOVAs were made on both the males' and the females' data. Results for males indicated a block effect ($F(1, 11) = 5.21$, $p < .05$) and a hand effect ($F(1, 11) = 12.55$, $p < .01$) but no significant block × hand interaction. These effects reflected, as previously, a greater number of units touched by the left hand (mean left = 3.13, SD = 1.56) than by the right (mean = 2.26, SD = 1.06) and a greater number of units touched during the first block of trials (mean first = 2.93, SD = 1.58; mean second = 2.46, SD = 1.16). The same analysis considering data of females revealed a significant touching hand effect corresponding to a greater number of cubes touched by the left hand than by the right (mean left = 1.45, SD = .35, mean right = 1.28, SD = .21; $F(1, 11) = 4.96$, $p < .05$). No other main effects or interactions were statistically significant. In short, hand differences in terms of the number of cubes touched were apparent, both for males and for females, at the first contact of the hand with the shape.

Relations between Performance and Exploratory Strategies

We verified whether accuracy was linked to our indices of exploratory strategies (number and duration of exhaustive explorations, number of cubes touched simultaneously). ANOVAs were performed, independently for male and female data, with the outcome of the recognition phase (success or failure) as the unique within-subjects factor. Block and hand variables were not included because earlier analyses showed that they were independent on the accuracy measurement. No significant effect emerged from these comparisons, which indicates that the outcome of the trials is not directly linked to our indices of exploratory strategies.

Correlational Analyses

Table 3 provides the matrix of correlations (r Bravais–Pearson) for males and for females between accuracy, duration, and number of explorations as well as the number of cubes touched simultaneously. These correlations were computed by averaging, for each subject, the data corresponding to the selected variable.

Accuracy was never significantly correlated with the three other measures. The number of explorations was negatively correlated with the duration. Similarly, the duration of explorations was negatively corre-

TABLE 3
Matrix of Correlations for Males and for Females for Accuracy and Exploratory Strategy Factors

	Number of explorations	Duration of explorations	Number of touched cubes
Males			
Accuracy	.32	−.31	−.07
Number of explorations		−.51†	−.10
Duration of explorations			−.64*
Females			
Accuracy	.13	−.15	.14
Number of explorations		−.91*	.78*
Duration of explorations			−.86*

* $p < .05$.
† $p < .10$.

lated with the number of touched cubes. Finally, a positive correlation was found in females, but not in males, between the number of exhaustive explorations and the number of touched cubes.

To summarize, for males, the more cubes were touched, the shorter the explorations became and a greater number of explorations were made. This pattern was almost identical in females except that the number of touched cubes seemed not to depend on the number of exhaustive explorations. Nevertheless, for both sexes, there was no direct relationship between the accuracy level and the indices of exploration.

DISCUSSION

Right-handed subjects had to monohaptically investigate out-of-sight nonsense stimuli and then recognize their drawing on a visually presented board. The apparatus recorded hand contacts on each of the eight cubes composing the stimulus. These contacts provided spatial and temporal information about manual exploratory strategies. The accuracy of the recognition phase was also recorded. Data on 12 males and 12 females can be summarized as follows. For accuracy, the only significant effect was a touching hand × pointing hand interaction that corresponded to a better performance in the ipsilateral combinations (touching and pointing with the same hand) than in the contralateral combinations (touching with one hand, pointing with the other). For exploratory strategies, we found no hand difference, both for males and females, in terms of number and duration of exhaustive explorations. However, in males, the left hand explored simultaneously more cubes on average than the right, and that result is already apparent when the very first contact of the hand with the shape is considered. In females, results indicated that the left hand tended to touch a greater number of cubes than the right. Moreover, a significant hand difference was found with the left hand touching more cubes than the right during the first contact. Finally, mean accuracy was never significantly correlated with data obtained on the exploratory strategies.

Analysis of Performance

The outcome of the recognition phase (accuracy) was independent of which hand was touching and which hand was pointing. These results are in agreement with findings of other studies (for touching, e.g., Adams & Duda, 1986; for pointing, e.g., Duda & Adams, 1987). However, our data contradict reports showing a greater accuracy when the left hand was used to touch the shape. Moreover, several authors (e.g., Dawson, 1981) have reported better performance in males compared to females for haptic discrimination. In our study, males performed better on average than females (see Table 2) but this sex difference was not significant. Several factors such as the complexity of the task (Fogliani, Fogliani-Messina, Barletta, & Caruso, 1982), the instruction given to the subject (Webster & Thurber, 1978), the level of subject's spatial ability (Posluszny & Barton, 1981), or a memory factor (Hannay & Smith, 1979) could account for the absence of accuracy effect. However, among these factors, one should emphasize the possibility to use a left hemispheric processing by referring to verbal labels to solve the task. Such a left hemisphere involvement could have counterbalanced a right hemisphere involvement due to the spatial components of the task. In effect, several of our subjects reported utilizing such strategies, for example by applying letter names to parts of the shape.

The highest accuracy scores found in the ipsilateral touching–pointing combinations is reminiscent of results from Gardner, English, Flannery, Hartnett, MacCormick & Wilhelmy (1977) and Adams & Duda (1986). In these studies, the subjects were more accurate when the same hand was used to touch and then to point toward the visual array. These authors employed a dichhaptic procedure. Gardner and Ward (1979) referred to a stimulus–response (S–R) compatibility effect to explain their previous results. S–R compatibility effects could not occur in our study because the single stimulus was presented in the median plane of the subject. Two other explanations may be proposed. The first one refers to an "activation," or a "priming," effect. The hand used for pointing was allocated prior to each block of trials. The subject could then program in advance the hand used for pointing. That precuing would have activated, or primed, the responding hemisphere, and such activation or priming would have led to more efficient attention on and processing of the information being presented in that hemisphere. The second interpretation, rejected by Gardner and Ward (1979), is that ipsilateral combinations led to higher accuracy scores because sensory inputs and motor outputs have been processed by the same hemisphere. Contralateral touching–pointing conditions, using longer neuronal pathways, implied an interhemispheric transfer and possibly a loss or a degradation of the information to be processed. Further experiments, for example by specifying the responding hand once the subject has touched the form, are needed to evaluate the validity of these two hypotheses.

Analysis of Exploratory Strategies

The literature is replete with reports showing differential abilities of the left and right hemispheres. The left hemisphere is classically said to be specialized for sequential, analytic processing, the right hemisphere for parallel, holistic processing (for a review: Bradshaw & Nettleton, 1981). For Hellige (1990), these theories suffer a lack of experimental validation. As pointed out by Sergent (1982), right hemispheric advantages, for example in terms of response time, are often used to support the holistic hypothesis, but in these cases, the holistic procedure by itself is not demonstrated.

In the haptic domain, a sequential–analytic procedure implies a systematic investigation of the features of the form. By contrast, a parallel–holistic procedure implies the simultaneous investigation of several characteristics of the shape. One could think that the number of cubes simultaneously touched is a good approximation of the quantity of information treated in parallel. That variable could thus allow experimenters to infer the kind of cognitive treatment that subjects adopt. In males, we found a significant hand effect for that factor. In females, the effect was close to significance. For both sexes, it was the left hand (right hemisphere) that touched the greatest number of cubes and thus was likely to process the greatest amount of information in parallel. Our results are thus globally congruent with the sequential–analytic/parallel–holistic framework. However, strictly speaking, a typical sequential procedure would imply the investigation of one feature of the form at a time (e.g., one angle). In our task, this should be translated by the simultaneous touch of one to two cubes at a time on average. In practice, the average number of cubes touched by the right hand was far greater than one to two both for males (5.22) and for females (4.05), which demonstrates that the right hand (left hemisphere) did not adopt a true analytic procedure. That consideration leads us to reject the strict analytic–holistic dichotomy. Given that, on average, the two hands simultaneously explored a large number of units, it seems that the two hemispheres adopted a holistic strategy, but that the right hemisphere processed the task more holistically than the left.

Hand differences in the number of cubes simultaneously touched were found to be significant in males. A nonsignificant trend in the same direction was observed in females. Considering the first hand contact on the shape, hand differences were significant for both sexes. However, the magnitude of hand differences was greater in males than in females. These results suggest weaker interhemispheric differences in the former than in the latter. Such differences have already been suggested by others (e.g., McGlone, 1980).

The Independence between Performance and Exploratory Strategies

We found no relation between the accuracy scores and the exploratory strategies (see Table 3). This result does not imply that the strategy is never linked to the performance, and we believe that there are experimental situations in which these measurements could be found to be linked.

The present intermodal study involved two sensorial modalities: tactual and visual. The final output of the recognition phase was thus influenced by the way both tactual and visual information were processed. Consequently, laterality effects either at the tactual or at the visual level, could be masked if the accuracy measurement is only considered, because accuracy emerges from the combination of two partially distinct processes.

Concluding Remark

Several authors have questioned the usefulness of a study of haptic discrimination to capture interhemispheric abilities (e.g., Duda & Adams, 1987). Given the low sensitivity of the accuracy measurement, the most commonly used dependent variable, caution is advised for generalizing from the numerous works that found no laterality effect. At least from this study, exploratory strategies seems to be more sensitive to laterality effects than accuracy. Moreover, the exploratory strategies more directly reflect specific procedure of each hemisphere, and their study provides a different perspective on hemispheric particularities.

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