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PAPER

Relationship between manual preferences for object manipulation and pointing gestures in infants and toddlers

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Abstract

The aim of this study was to measure the pattern of hand preferences for pointing gestures as a function of object-manipulation handedness in 123 infants and toddlers (10–40 months). The results showed that not only right-handers but also left-handers and ambidextrous participants tended to use their right hand for pointing. There was a significant correlation between manual preferences and pointing lateralization. Further analyses showed that the correlation between these two indexes was at its strongest during two key phases of language development (i.e. vocabulary spurt and syntax improvement) and weakened to become nonsignificant in the interim. These findings support the view that humans have a specialized area for communicative gestures and language in the left cerebral hemisphere that may be independent of the system controlling the purely motor functions of hand use.

Introduction

Over the past 25 years, several authors have studied manual preferences for object manipulation and the laterality of communicative gestures from a developmental perspective. Their results have shown a clear right-handed preference from infancy, for both manipulative actions (e.g. Ramsay, 1985; Fagard, 2001) and communicative gestures (e.g. Bates, O'Connel, Vaid, Sledge & Oakes, 1986; Blake, O'Rourke & Borzellino, 1994; Kimura, 1973), but while some authors (Bates *et al*., 1986; Young, Lock & Service, 1985) have investigated the two forms of laterality in individual children, there has apparently not been any research on their correlation in populations of young participants. In the present paper, the concept of 'communicative gestures' will be used to contrast with the concept of 'manipulative actions'. Communicative gestures refer to deliberate gestures, such as depictive (or 'symbolic') gestures used to imitate an action or deictic gestures such as pointing, as well as to non-deliberate gestures that are produced during verbal productions.

The literature on the development of laterality for object manipulation (i.e. handedness) can be briefly summarized by saying that it cannot be reduced to the mere expression of an innate motor function, even if asymmetries are already present in intra-uterine life (Hepper, Wells & Lynch, 2005). Handedness develops according to the age of the individual (Dellatolas, De Agostino, Jallon, Poncet, Rey & Lellouch, 1988; Fagard, 2001) and is influenced by (1) the positions of the object to catch and the experimenter in the environment (Butterworth, Franco, McKenzie, Graupner & Todd, 2002; Carlson *et al*., 1985), (2) the object's shape and size (Harris & Carlson, 1988), (3) the type of manipulation required (Fagard & Marks, 2000) and (4) the participant's prior experience with the object (Dellatolas, Tubert-Bitter, Curt & De Agostini, 1997; De Agostini, Curt & Tzortzis, 1999).

Laterality for communicative gestures is also influenced by environmental parameters (Butterworth *et al*., 2002), but seems to emerge and stabilize much earlier than handedness for manipulating objects. For Locke, Bekken, McMinn-Larson and Wein (1995), gestures and language could be linked before the advent of clear communicative gestures like pointing, as the emergence of babbling at around 6 months of age is associated with an increase in the activity of the right hand (Ramsay, 1985, but see Iverson, Hall, Nickel & Wozniak, 2007). Iverson and Thelen (1999) showed that when language develops, with the appearance of first words, the pointing gesture becomes the main manual communication gesture integrating body movements with language. This is the reason why we are interested in the investigation of this particular gesture. Pointing appears on average at the age of about 11 months (Butterworth & Morissette, 1996) and is clearly related to language, or at least to the intention to communicate, as it is only used if there is a social partner in the room (Franco & Butterworth, 1996). Pointing is positively

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correlated with language development (Volterra, Caselli, Capirci & Pizzuto, 2005). In addition, according to Iverson and Goldin-Meadow (2005), young children start using what are called ‘supplementary combinations’, that is combining a word and a pointing gesture to mean things (e.g. pointing to a dog and saying ‘sleep’ to convey the message that the dog is sleeping), about 4 months before they are able to combine two words to express that same meaning (in this example, ‘dog sleeps’). The use of such combinations does not end once the vocabulary spurt is over but, on the contrary, significantly increases afterwards (Özçaliskan & Goldin-Meadow, 2004). These additional combinations are the precursors of the appearance of more complex linguistic constructions. Based on the literature, then, a first conclusion is that the two types of laterality do not become stable at the same point in development.

To what extent could hand preferences and a communicative gesture like pointing nevertheless be linked? Bates *et al*. (1986) showed that infants and toddlers perform symbolic activities (games like pretending to pick up the telephone) and pointing more frequently with their right hand than they do manipulative actions. Moreover, autistic children (who have difficulty communicating) do not seem to display this more pronounced right-handed preference, and it could be because their communicative gestures are less lateralized than those reported in the general population (Bonvillian, Gershoff, Seal & Richards, 2001).

Communicative gestures thus appear to be performed more with the right hand than non-communicative actions. Bates *et al*. (1986) explained this difference by referring to Kinsbourne and Hiscock’s theory (1983), namely that laterality of symbolic gestures could reflect the existence of an interference/facilitation dynamics between language and lateral hand control within the language areas of the brain. This would generate competition in the allocation of left hemisphere resources to the motor and language functions. When a gesture is symbolic, that is when it can replace a word, as in the case of pointing, it is not in competition with language, and its right laterality is actually facilitated because the left hemisphere is already mobilized. By contrast, a non-symbolic gesture does compete with language, and language functions therefore tend to inhibit the use of the right hand for manipulative actions.

Another way of explaining this laterality difference between the two types of hand activities is to posit the existence of two different systems: (1) an integrative system for communicative gestures and language, and (2) an independent system devoted to the purely motor functions of manipulation. It is indeed highly likely that communicative gestures involve the same brain areas as speech (Kimura, 1993), in contrast to object manipulation.

A number of different arguments support the theory of an integrated language-communicative gestures system. For example, using evoked potentials, Özyürek, Willems, Kita and Hagoort (2007) showed that the brain simultaneously integrates speech and co-speech gestures. According to Bernardis and Gentilucci (2006), language and communicative gestures are coded as a single signal. Furthermore, during manipulative and gesturing activities, infants’ vocalizations are modulated by the size of the object (Bernardis, Bello, Pettenati, Stefanini & Gentilucci, 2008): the voice frequency spectrum increases when infants gesture to obtain a large object rather than a small one. This suggests that pointing and vocalizations are linked, and confirms what Iverson and Thelen (1999) stressed, namely, that language and gestures share cerebral mechanisms with parts of Broca’s area that are activated during certain hand movements and facial expressions. It has also been shown that in deaf people, sign language is coded by the language areas in the left hemisphere (e.g. Corina, Vaid, & Bellugi, 1992; Emmorey, Mehta & Grabowski, 2007; Grossi, Semenza, Corazza & Volterra, 1996).

This set of findings is consistent with Trevarthen’s (1996) hypothesis that language areas’ laterality is a developmental process arising from a functional asymmetry of the cerebral hemispheres. This author found that an infant’s gestures allow him/her to engage in a ‘proto-conversation’, with the gestures usually being made with the right hand. The asymmetry generates adaptive behaviors that permit communication with the social environment. The results of a study by Petitto, Holowka and Sergio (2001) would appear to validate this hypothesis: hearing infants born of deaf parents produced a ‘silent babbling’, namely, gestures with a rhythmic pattern reminiscent of standard babbling (‘bababa’). Their silent babbling reproduced the rhythmic frequencies that characterize natural language and differed from other gestures.

The above set of studies argues in favor of a single, integrated system comprising communicative gestures and language. As such, it appears to contradict the alternative theory suggested in the paper by Bates *et al.* (1986), which implies two distinct systems, a motor system and a speech-processing system.

The aim of the present study was to find out whether right-hand preferences for a communicative gesture such as pointing can nevertheless be predominantly explained in infants and toddlers by the use of their preferred hand for manipulations. We hypothesized that if there is a common brain area for language and communicative gestures in the left cerebral hemisphere, manipulative actions and communicative gestures such as pointing would not be strongly related within the same individual. A close-to-zero correlation would, in effect, suggest that most of the variance cannot be accounted for by links between the two variables (i.e. manipulative hand preference and pointing laterality). However, there might still be a correlation simply because both types of laterality are expressed through the same effectors (the hands). Given that a correlation of .5 or above (explaining at least 25% of the variance) is regarded as strong, we expected to obtain a weak (explaining about 1% of the variance) to moderate correlation (explaining about 10% of the variance) between the two variables. Furthermore, if each type of laterality is controlled by a separate cerebral system, we could expect ambidextrous and left-handed participants to point with their right hand.

Method

Participants

There were 123 participants (65 girls and 58 boys), aged between 10 and 40 months. They were tested in four day-care centers in Marseilles, France. Although our aim was not to check for the influence of age on laterality patterns, in order to make the distribution of ages more readable, the population was divided into five subgroups (see Table 1).

One hundred and nine participants were tested for handedness on three bimanual tasks (three trials per task) and one complex unimanual task (three trials per task). Of these 109 participants, 43 were tested on an additional, simple unimanual task (three trials per task).

Other participants from a previous pilot study were taken into account to clarify correlations with language development, for which there were not enough participants (see below). We only included participants from this previous study who had been tested on at least two of the three bimanual tasks ('Bottle' and 'Ring'; see below), with three manipulation trials and seven pointing trials. This gave us 14 additional participants, making for a total of 123 participants.

Apparatus

Young *et al*. (1985) investigated the use of the left and right hands by infants and their mothers for picking up objects and making communicative gestures, with the goal of showing that right-handedness for communicative gestures is not learned in the environment. However, it was later demonstrated (see below; Fagard, 2001) that unimanual grasping actions are a poor index of handedness. Moreover, the communicative gestures studied by Young *et al*. (1985) not only included pointing but also offering objects to others, which we consider an ambiguous gesture because it encompasses a grasping action which is then used in a communicative context.

Table 1 *Age groups, standard deviation and number of participants in each group*

Age	Mean age	*SD*	*n*
10–15 months	12.4	1.5	19
16–21 months	19	1.6	28
22–27 months	24	1.6	30
28–33 months	30	1.8	33
34 – 40 months	36	1.8	13
Total population	24	7.4	123

Accordingly, although our study drew on Young *et al*.'s initial work, we used other tasks described in the more recent literature. To establish manual preferences for object manipulation in our participants, five tasks partly based on the ones employed by Fagard and Marks (2000) were used. We then tested our participants' laterality for two communicative gestures, pointing to a book and pointing to objects in the immediate environment.

The three tasks assessing handedness for object manipulation were bimanual activities, in which the preferred hand plays an active role and the non-preferred hand is used as a passive support or for orientation (Fagard, 2001). Compared with unimanual grasping, which can be performed equally simply with either the right or left hand, regardless of handedness, bimanual activities are a more reliable indicator of handedness (Fagard, 2001) because each hand has a specific role, so a lateralized strategy is required.

Fagard and Marks (2000) showed that bimanual tasks are more or less lateralized, depending on the type of manipulation required of each hand: the more the role of the so-called 'passive hand' is limited to supporting, the more the task tends to be performed with the right hand. On this basis, tasks can be classified as a function of how passive the passive hand is and what action is to be performed with the active hand. In Fagard and Marks's (2000) study, the actions that elicited the most right-handed patterns were 'orienting ⁄ unscrewing' and 'holding ⁄ pulling' (each 70% right-handed). As the purpose of the present study was to find out whether the laterality of communicative gestures can be explained by handedness, we deliberately choose tasks requiring these more right-handed patterns of actions.

1. The 'bottle' was a small, empty, transparent plastic bottle (20 cm high and 6 cm in circumference), with a plastic cap to unscrew (orienting/unscrewing). Every attempt to unscrew it was counted, regardless of whether or not it was successful.
2. The 'ring' was a plastic ring which had to be removed from a Fisher-Price column. The ring was pushed down just far enough to require the participant to hold the base with one hand (holding/pulling), although this did not require any strength to be applied.
3. The 'tube' was a small transparent plastic bottle (6 cm in diameter) cut off at a height of 14 cm, in which a soft toy (approx. 12 cm × 4 cm × 6 cm) had been placed. The participant had to hold the tube with one hand in order to take the toy out with the other (holding/pulling).

Two unimanual tasks were added in order to check for the stability of handedness:

4. In the 'complex unimanual manipulation' task (UNIC; Fagard, personal communication, December

2006), the experimenter held out a transparent plastic tube (14 cm × 6 cm) to the participant. The open end of the tube was facing the participant who had to slide a hand inside it in order to take out a small soft toy (5 cm × 3 cm × 2 cm) placed at the end of the tube. In this way, the child had to use his/her preferred hand for performing this unimanual task.

5. In the 'simple unimanual task' (UNIS), the participant had to grasp the cap of a bottle. The cap was lying on the table in front of the toddlers or on the floor for infants less than 12 months old.

Procedure

Each participant was seated in front of a table (child-size furniture was used). The youngest participants (under 12 months) were seated on the floor because we could not do any differently in the daycare centers. To avoid postural biases, we collected data only when the participants had their legs stretched out on the floor and both arms at their sides without leaning more on one limb than on the other. We also made sure that the children seated on a chair had their hands and arms free (hands by their sides or on the table) and were not holding onto the table or grasping any other object.

Before the test began, all the toys were presented to the participants for familiarization and for clarifying the vocabulary, alternating right and left hands. The five object manipulation tasks were presented at least three times. These 15 trials (5 tasks*3 trials) were presented randomly.

For the pointing tests, two tasks were administered. The first consisted in asking the participant to point with his/her finger to the characters depicted in a book (five trials; the participant could not touch the book). The second task consisted in pointing to toys (five trials) placed in the immediate environment, about 1.5 meters away from the participant. The toys and characters involved in these tests were introduced to the participants before each trial started.

The test objects were located on the table (or on the floor in front of the feet for the youngest participants) across from the child's sagittal midline level. During the task requiring participants to point to a book, we noticed that visual-field dependency was very obvious in the young participants: they tended to point to a character on the right page with the right hand and on the left page with the left hand. For this reason, we placed the page showing the character of interest on the child's sagittal midline, rather than the book, and far enough away to avoid its manipulation.

The experimenter sat in front of the participant for the handedness tests, and to avoid a laterality bias, stood behind him/her for the pointing tasks (e.g. Bonvillian *et al*., 2001). The experimenter alternated between the use of the right and left hands when she held the book from behind the participant. Note that most of our tasks (object manipulation and pointing) have already been used with populations of comparable age. None of our participants had any difficulty performing the tasks proposed. Finally, to avoid a learning bias, the order of the tasks (object manipulation and pointing preferences) was alternated across participants.

Data analysis

An individual handedness index (HI) was calculated for each participant using the formula R−L / (R+L), where R and L stand for the total right-hand and total left-hand responses. The HI values varied from −1 to 1, with the sign indicating hand-preference side and the absolute value reflecting hand-preference strength. Although handedness varies along a continuum (Annett, 1976), this score was used to classify participants as left-handed ($z < -0.5$), right-handed ($z > 0.5$), or ambidextrous ($-0.5 < z < 0.5$).

Results

Correlations between handedness indexes

As mentioned in the Apparatus section, Fagard and Marks (2000) showed that handedness patterns are influenced by the type of manipulation required in the task, so we checked to see whether our tasks were correlated. As shown by the results in Table 2, we obtained significant correlations between the 'bottle' and 'ring' ($r = 0.6$, $p < .01$), 'bottle' and 'tube' ($r = 0.7$, $p < .01$) and 'ring' and 'tube' ($r = 0.6$, $p < .01$, bimanual indexes).

The complex unimanual manipulations (UNIC) were also significantly correlated with the three bimanual manipulations (bottle, ring, tube) but less strongly so ($r = 0.3$, $r = 0.4$ and $r = 0.4$, respectively, $p < .01$). These tasks were therefore not taken into account in calculating the overall index of handedness, as they might have decreased the strength of right laterality for a given individual. A correlation of 0.3 explains only 9% of the variance, so we only considered correlations of at least 0.6 (explaining 36% of the variance).

Table 2 *Correlations between manual preferences indexes*

		HI ring	HI tube	HI unic	HI unis
HI bottle	Pearson correlation	.599*	.743*	.304*	.508*
	n	123	109	109	43
HI ring	Pearson correlation		.601*	.359*	.218
	n		109	109	43
HI tube	Pearson correlation			.417*	.480*
	n			109	43
HI unic	Pearson correlation				.704*
	n				43

Note: HI = Handedness Index, UNIC = Complex unimanual task, UNIS = Simple unimanual task. * Correlation significant at 0.01 (two-tailed).

The simple unimanual task (UNIS) was significantly correlated with UNIC ($r = 0.7$, $p < .01$) and also with 'bottle' ($r = 0.5$, $p < .01$) and 'tube' ($r = 0.5$, $p < .01$), but not with 'ring' ($r = 0.2$, *ns*). These correlations justified the use of an overall index we called BRT (bottle, ring, tube) as an overall handedness index.

Percentages of types of laterality

Sixty-eight participants (55%) were characterized as right-handers, 25 (20%) as left-handers, and 30 (25%) as ambidextrous, based on the BRT handedness scores. Regarding manual preferences for pointing, 78 participants (63%) were characterized as right-handers, 11 (9%) as left-handers, and 34 (28%) as ambidextrous. Thus, 73% of the participants who were lateralized for object manipulation ($n = 93$) and 88% of those lateralized for pointing ($n = 89$) were right-handers.

Overall use of the right hand was observed for both kinds of task (see Figure 1). These biases were confirmed by the Mean Handedness Index (M.HI), standard deviations and one-sample *t*-tests (two-tailed) for object-manipulation handedness (M.HI = 0.32, $\sigma = 0.73$, $t(123) = 4.92$, $p < .001$) and communicative-gesture handedness (M.HI = 0.52, $\sigma = 0.56$, $t(123) = 10.34$, $p < .001$).

Potential effects of age and gender

Potential effects of age and gender were assessed using a multivariate ANOVA with the manipulation handedness scores and pointing scores as dependent variables and gender and age groups as independent variables. The only significant effect was that of age on manipulation handedness ($F(1, 121) = 3.12$; $p < .02$). This influence may reflect an increase in the percentage of right-handers with age, except in the oldest group (34–40 months), which had more left-handers than right-handers but only a small number of participants ($n = 13$): 42%, 57%, 60%, 67%, 31% of right-handers per group in increasing order of age. All other effects were non-significant (effect of age on pointing: $F(1, 121) = 0.82$; $p > .05$; effect of gender on handedness: $F(1, 121) = 0.94$; $p > .05$; effect of gender on pointing: $F(1, 121) = 3.31$; $p > .05$; effect of the interaction of gender and age on handedness: $F(1, 121) = 1.32$; $p > .05$; effect of the interaction of gender and age on pointing: $F(1, 121) = 0.53$; $p > .05$).

An age-by-task ANOVA (Age*Bottle, Age*Ring and Age*Tube) showed that this effect was due to the 'bottle' ($F(4, 118) = 3.8$; $p < .006$) and 'tube' ($F(4, 118) = 4.44$; $p < .002$) scores, whereas age had no influence on the 'ring' score ($F(4, 118) = 1.3$; $p > .05$). Moreover, a post-hoc Scheffé analysis indicated that the effect was due to the difference between Groups 4 and 5 for the 'bottle' ($F(4, 118) = 0.27$; $p < .03$) and 'tube' ($F(4, 104) = 0.25$; $p < .02$) tasks, that is a difference from 34 months onwards. As indicated above, Group 5 had only 13 participants, seven of whom were left-handers for object manipulation. In all likelihood, therefore, this last group skewed the results, and age actually had little or no influence on these bimanual tasks.

Relationship between handedness indexes and pointing laterality

Although there was a significant correlation between manual preferences and pointing lateralization ($r = 0.4$, $p < .01$, $n = 123$), handedness for object manipulation accounted for just 15% of pointing laterality (adjusted $R^2 = 0.15$).

The number of right-handed participants was higher in pointing ($n = 78$, representing 63% of the sample) than in object manipulation ($n = 68$, 55%), and this difference was significant (one-sample *t*-test, two-tailed $t(123) = 3.97$, $p < .001$). Moreover, as shown in Figure 2, 36% of the participants characterized as left-handed in object manipulation became right-handed when pointing, and 40% became ambidextrous. Among the ambidextrous participants, 53% pointed with their right hand and only 10% became left handed. By contrast, only 3% of the right-handers shifted to the left hand for pointing, whereas 78% remained right-handers. These laterality changes were statistically significant ($\chi^2 = 18.87$, $p < .001$).

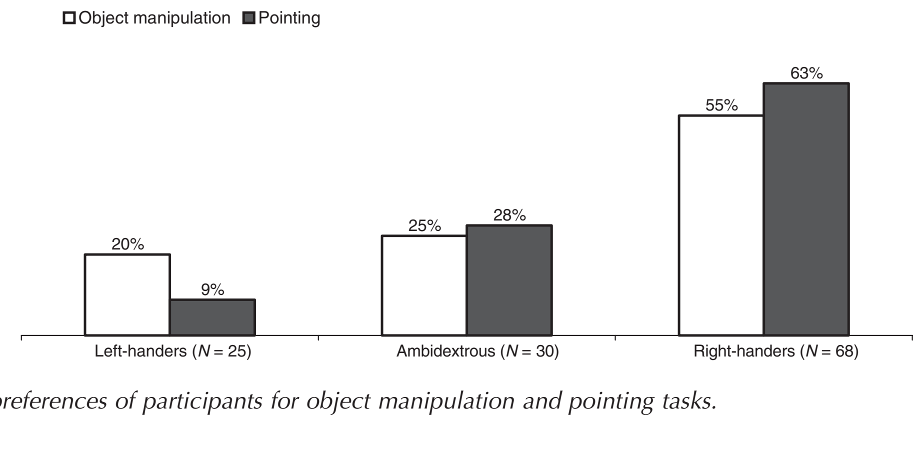

Figure 1 *Manual preferences of participants for object manipulation and pointing tasks.*

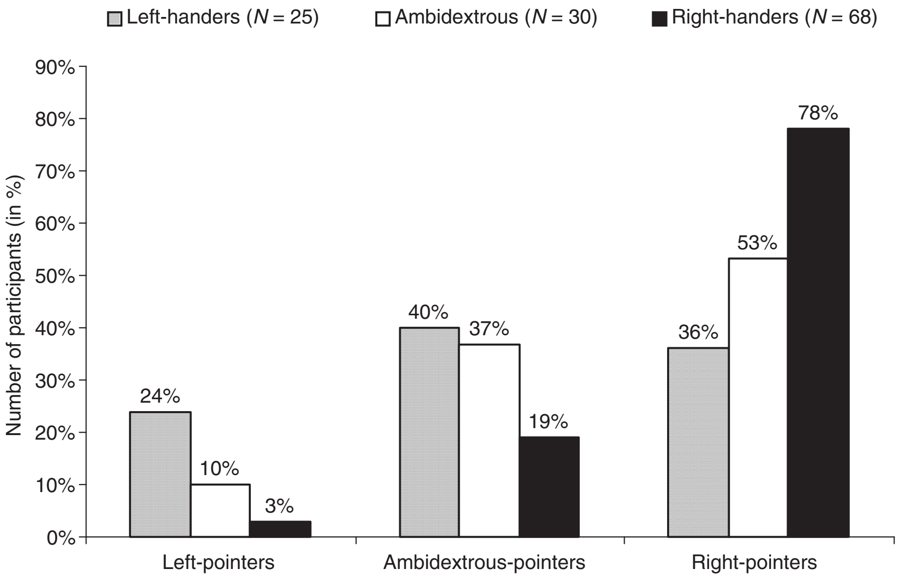

Figure 2 *Distribution of manual preferences for pointing as a function of manual preferences for object manipulation.*

Different correlations at different stages of language development

Figure 3 shows that from 21 months onwards, the percentage of right-handed pointers was always higher than the percentage of right-handed object manipulators.

Further analyses (see Table 3 and Figure 4) showed that the correlation between handedness and pointing preferences was strongest between the ages of 18 and 20 months (r = 0.7, R^2 = 0.51, p < .01), which is the period considered to encompass the vocabulary spurt, and between 29 and 32 months of age (r = 0.8, R^2 = 0.65, p < .01), which is when syntax improves (according to Bates *et al.*, 1986, 28 months is the midpoint of a burst in the acquisition of grammatical morphology and we assumed that after 28 months of age, all the participants had entered this period of syntax development). This correlation weakened, to the point of becoming non-significant, in the interim periods: 10–17 months (r = 0.3, R^2 = 0.12, *ns*), 21–28 months (r = 0.1, R^2 = 0.01, *ns*) and 33–40 months (r = 0.4, R^2 = 0.17, *ns*). Regression analyses, in which handedness for object manipulation predicted pointing laterality but only during the vocabulary spurt (F(1, 14) = 13.65; p < .003) and the syntax-development period (F(1, 19) = 35.13, p < .001).

Table 3 *Percentage of right-handers and correlation between object manipulation and pointing*

Age in months	*N*	Right-handers in % Handedness	Pointing	Pearson *r*	% of Variance	Sign
10–17	25	52	48	0.3	11	ns
18–20	15	60	53	0.7	51	0.01
21–28	45	58	71	0.1	1	ns
29–32	21	71	76	0.8	65	0.01
33–40	17	30	59	0.4	17	ns

Discussion

The fact that a given participant will preferentially use his/her right hand for communicative gestures rather

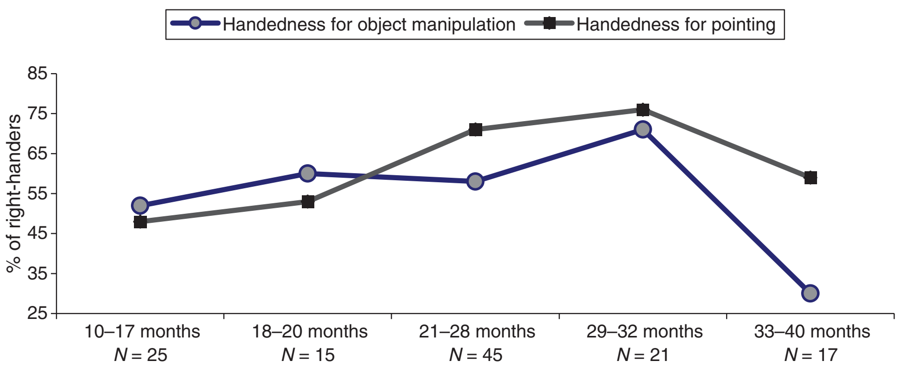

Figure 3 *Percentage of right-handers for object manipulation and pointing between 10 and 40 months of age.*

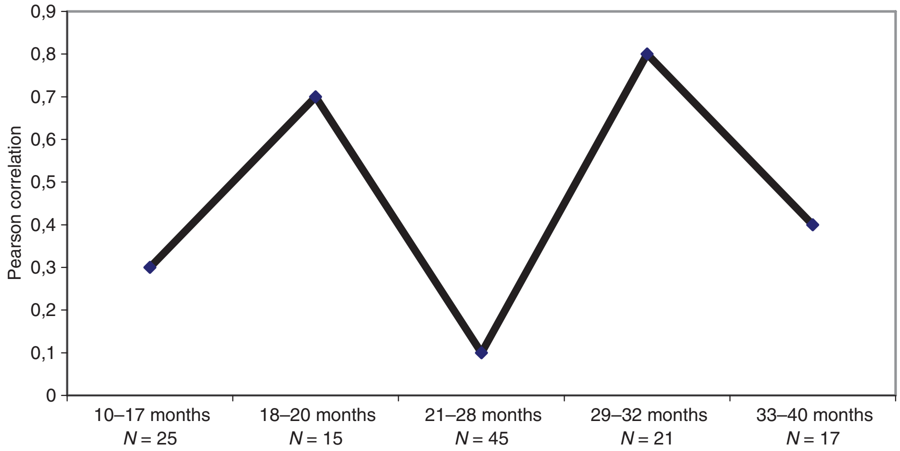

Figure 4 *Correlation between object manipulation and pointing as a function of two language-development phases (vocabulary spurt and syntax improvement).*

than for object manipulation has already been demonstrated in human infants and toddlers (Bates *et al*., 1986; Bonvillian, Richards & Dooley, 1997) and also in nonhuman primates (adult chimpanzees: Hopkins, Russell, Freeman, Buehler, Reynolds & Schapiro, 2005; adult baboons: Meguerditchian & Vauclair, 2006; Vauclair, Meguerditchian & Hopkins, 2005). However, the search for a correlation between these two laterality indexes has, to our knowledge, only ever been attempted for nonhuman primates, never humans. Chimpanzees and baboons have been found to exhibit only a non-significant within-individual correlation of hand preferences between communicative gestures and bimanual object manipulations (for baboons: Meguerditchian & Vauclair, 2006; for chimpanzees: Hopkins *et al*., 2005).

In contrast to this evidence for monkeys and apes, the results of the present study of infants and toddlers revealed the existence of a significant correlation between handedness for object manipulations and laterality of communicative gestures within the same participant. One could conclude that these two types of laterality are interdependent, and that an individual will tend to point with his/her right hand because he/she is preferentially right-handed for manipulating objects. However, given that only 15% of the variance was explained by the correlation, meaning that 85% of the variance was not explained by the relationship between handedness and pointing laterality, this suggests that the two lateralities are only partially linked. Moreover, our results demonstrate that a large proportion of the left-handed and ambidextrous participants pointed with their right hand. These results confirm previous data reported by Kimura (1973): right-handers tend to gesture with their right hand when speaking, whereas left-handers fail to display the same tendency (i.e. speech associated with gestures by the left hand). Finally, our results showed that the correlation between the two indexes was strong and significant during only two key phases of language acquisition, namely the vocabulary spurt and the period during which syntax improves.

As suggested in the introduction to this paper, differences in laterality patterns have been explained with reference to two hypotheses. The first hypothesis, set forth in Bates *et al*.'s (1986) article, implies the existence of a single bilateral motor system for communicative gestures and object manipulations. In the event of cognitive overload, however (e.g. during a key phase of language acquisition), language takes over. The second hypothesis is based on the idea of an integrated system of communication (e.g. Bernardis & Gentilucci, 2006; Iverson & Thelen, 1999; Özyürek *et al*., 2007) and postulates the coexistence of two different systems: one system is purely motor and controls object manipulation, while the other is in charge of both vocal and gestural communication. This theory is consistent with the results reported by Locke (2007), showing that pointing increased the quantity of vocal activity in 16.5-month-old infants when their behavior implied communicative intentions.

It is difficult to decide which hypothesis is most plausible on the strength of our findings. Nevertheless, the results we obtained for ambidextrous and left-handers tend to support the idea that the brain areas controlling object manipulation differ from those controlling communicative gestures. A large proportion of the left-handed and ambidextrous participants pointed with their right hand. If the motor functions of the hands shared the same cerebral system as communicative gestures, insofar as they would necessarily involve the language areas as well, we would expect left-handedness for manipulation to be associated with contralateral cerebral dominance for language functions (i.e. right-hemisphere dominance). However, 70% of left-handers for manipulations also have left cerebral control of language (Knecht, Dräger, Deppe, Bobe, Lohmann, Flöel, Ringelstein & Henningsen, 2000), which supports the idea that the neural substrates of communicative gestures and manipulative actions differ by virtue of the fact that language areas are involved in gestural communication but not in motor functions.

Furthermore, if two systems (one purely motor and another purely vocal) were in competition, they would probably influence each other, even outside periods of important linguistic development. However, the weak and non-significant correlations we obtained suggest that during the intermediate periods there are only loose links between manual preferences for object manipulation and laterality for pointing.

Investigations into the hand preferences of nonhuman primates have brought some new elements into this debate. Captive chimpanzees and baboons show a marked preference for the right hand, not only for bimanual manipulation (chimpanzees: Hopkins, 1995; baboons: Vauclair *et al.*, 2005) but also at a higher degree, for the production of communicative gestures[1] (in chimpanzees: Hopkins *et al.*, 2005; in baboons: Meguerditchian & Vauclair, 2006). In neither species are hand preferences for gestures within a given individual correlated with hand preferences for bimanual actions. These findings suggest that a specific left-lateralized communication system within the brain, different from the one involved in object manipulation, may control communicative gestures (Meguerditchian & Vauclair, 2006). Moreover, recent brain imaging research has shown that handedness for manipulations in chimpanzees is associated with asymmetries of the primary motor cortex (Hopkins & Cantalupo, 2004), while use of the right hand for communicative gestures is correlated with larger inferior frontal gyri in the left hemisphere, the equivalent of Broca's area (Taglialatela, Cantalupo & Hopkins, 2006). Additionally, the right preference for gestural communication in chimpanzees is reinforced when the gestures are associated with the production of attention-getting sounds (Hopkins & Cantero, 2003), suggesting continuity with humans concerning the existence of left-hemispheric control of a bimodal communicatory system (gestural and vocal) that differs from the mechanisms controlling the purely motor functions of manipulation.

While the concept of competition for left-hemisphere resources is unlikely for the reasons mentioned above, our interpretation would nonetheless be consistent with the idea of a facilitatory/inhibitory system, whereby the hypermobilization of the left hemisphere during key language-acquisition periods would facilitate the use of the right hand. Outside these periods, the right hand would be used less.

Moreover, we obtained an unexpected result, in that the two types of laterality were not correlated during the intermediate period from 21 to 28 months. Yet, between the lexical growth spurt and the organization of syntax, toddlers move from the production of single words to the production of entire sentences. Does this mean that this interim period is not a 'true' learning phase in which the child needs to reorganize his/her knowledge? Or is the intermediate stage just an extension of the vocabulary spurt, in which the toddler 'adds' words to pseudo-sentences of two or three words? If so, this stage would not generate a specific cognitive load and would therefore not significantly affect laterality patterns. The development of syntax, however, would necessitate major changes involving the reorganization of knowledge.

In conclusion, our research suggests that laterality for a communicative gesture like pointing is moderately linked to handedness for object manipulation. However, because these two types of laterality were highly correlated at crucial periods of language development, our results argue in favor of the hypermobilization of the left hemisphere for language functions during these critical periods. Moreover, in all 1157 trials of the pointing task performed by our participants, while one hand was pointing, the other hand did not move at all (it either hung down at the side of the body or else lay on the table). This last finding again suggests a hypermobilization of the left hemisphere during communication and reinforces the hypothesis that gestures (such as pointing) can serve as a fundamental tool in language learning (Iverson & Goldin-Meadow, 2005; Volterra *et al.*, 2005).

Additional studies with infants and toddlers are, of course, needed to assess their level of language comprehension and production at the same time as their hand preferences. Insofar as the purpose of this study was to analyze gestures alone, we did not test the participants' level of language understanding or production. Ideally, this kind of study should be undertaken with large samples of participants during key periods of language development.

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[1]These communicative gestures in chimpanzees consist of extending the arm to obtain food from humans (Hopkins *et al.*, 2005), and in baboons, of slapping the hand on the ground in the direction of a conspecific or human observer to threaten it (Meguerditchian & Vauclair, 2006).

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