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Hand shape, function and hand preference of communicative gestures in young children: Insights into the origins of human communication

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THÈSE

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Hand shape, function and hand preference of communicative gestures in young children: Insights into the origins of human communication.

Abstract:

Even though children's early use of communicative gestures is recognized as being closely related to language development (e.g., Colonnesi et al., 2010), the nature of speech–gestures links still needs to be clarified. This dissertation aims to investigate the production of pointing gestures during development to determine whether the predictive and facilitative relationship between gestures and language acquisition involves specific functions of pointing, in association with specific features in terms of hand shape, gaze and accompanying vocalizations. Moreover, special attention was paid to the study of hand preferences in order to better understand the development of left hemisphere specialization for communicative behaviors.

Our results revealed complex relationships between language, communicative gestures and manipulative activities depending on the function of gestures (i.e., imperative versus declarative pointing) as well as on specific stages of language acquisition. Declarative gestures were found to be more closely associated with speech development than imperative gestures, at least before the lexical spurt period. In addition, the comparison of hand-preference patterns in adults and infants showed stronger similarity for gestures than for object manipulation. The right-sided asymmetry for communicative gestures is thus established in early stages, which suggests a primary role of gestures in hemispheric specialization.

Finally, our findings have highlighted the existence of a left-lateralized communication system controlling both gestural and vocal communication, which has been suggested to have a deep phylogenetic origin (e.g., Corballis, 2010). Therefore, the present work may improve current understanding of the evolutionary roots of language, including the mechanisms of cerebral specialization for communicative behaviors.

Key words: *Gestural communication, Pointing, Young children, Hand preference, Hemispheric specialization, Origins of language.*

Forme, fonction et préférence manuelle des gestes communicatifs chez le jeune enfant : Comprendre les origines de la communication humaine.

Résumé :

Bien que l'utilisation précoce de gestes communicatifs par de jeunes enfants soit reconnue comme étant étroitement liée au développement du langage (e.g., Colonnesi et al., 2010), la nature des liens gestes–langage doit encore être clarifiée. Cette thèse a pour but d'étudier la production de gestes de pointage au cours du développement afin de déterminer si la relation prédictive et facilitatrice entre les gestes et l'acquisition du langage implique des fonctions spécifiques du pointage, en association avec des caractéristiques spécifiques en terme de forme de mains, regard et vocalisations. De plus, une attention particulière a été apportée à l'étude des préférences manuelles dans le but de mieux comprendre le développement de la spécialisation hémisphérique gauche pour les comportements communicatifs.

Nos résultats ont révélé des relations complexes entre le langage, les gestes communicatifs et les activités de manipulation, qui dépendent de la fonction des gestes (i.e., pointage impératif versus déclaratif) et des étapes spécifiques de l'acquisition du langage. Les gestes déclaratifs sont plus étroitement associés au développement de la parole que les gestes impératifs, au-moins avant la période d'explosion lexicale. De plus, la comparaison des patterns de préférence manuelle chez l'enfant et l'adulte a montré une plus grande proximité pour les gestes que pour la manipulation d'objet. L'asymétrie manuelle droite pour les gestes communicatifs est ainsi établie à des stades précoces, ce qui suggère un rôle primordial des gestes dans la spécialisation hémisphérique.

Finalement, nos résultats ont mis en évidence l'existence d'un système de communication dans l'hémisphère cérébral gauche contrôlant à la fois la communication gestuelle et verbale, qui pourrait avoir une origine phylogénétique ancienne (e.g., Corballis, 2010). Par conséquent, le présent travail peut améliorer notre compréhension des origines du langage, y compris des mécanismes de la spécialisation cérébrale pour les comportements communicatifs.

Mots-clés : *Communication gestuelle, Pointage, Jeune enfant, Préférence manuelle, Spécialisation hémisphérique, Origines du langage.*

List of papers

This dissertation is based on the following articles, which are referred to in the text by their roman numerals:

I **Cochet, H**., & Vauclair, J. (2010). Pointing gesture in young children: Hand preference and language development. *Gesture, 10*(2/3), 129-149.

II **Cochet, H**., & Vauclair, J. (2010). Features of spontaneous pointing gestures in toddlers. *Gesture, 10*(1), 86-107.

III **Cochet, H**., & Vauclair, J. (2010). Pointing gestures produced by toddlers from 15 to 30 months: Different functions, hand shapes and laterality patterns. *Infant Behavior and Development*, *33*, 432-442.

IV **Cochet, H.** (2011). Development of hand preference for object-directed actions and pointing gestures: A longitudinal study between 15 and 25 months of age. *Developmental Psychobiology* (in press).

V **Cochet, H**., Jover, J., & Vauclair, J. (2011). Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period. *Journal of Experimental Child Psychology* (in press). DOI. 10.1016/j.jecp.2011.04.009

VI **Cochet, H**., & Vauclair, J. (2011). Hand preferences in human adults: Non-communicative actions versus communicative gestures. *Cortex* (in press). DOI. 10.1016/j.cortex.2011.03.016

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One thing I have learned in a long life: that all our science, measured against reality, is primitive and childlike - and yet it is the most precious thing we have.

Albert Einstein

A jigsaw's falling into place...

General introduction

Gestures form such an integral and natural part of human communicative behaviors that they have been described as “a phenomenon that often passes without notice, though it is omnipresent” (McNeill, 2000, p. 1). The role played by gestures in communication, especially in language development has long been investigated, covering a wide range of topics from the relationship between gesture and thought to sign language acquisition. This dissertation focuses on the relationship between communicative gestures and language by adopting a two-fold approach. The first objective is to examine to what extent infants’ and children’s gestural communication can be regarded as an ontogenetic foundation for verbal communication. The second objective is to address the question of the evolutionary foundations of human language, using the study of speech–gesture links in infancy as the starting point of inferences about language origins.

These issues have been investigated in the present work with special emphasis on the study of hand preferences for communicative gestures. Although it may provide valuable insights into the mechanisms of cerebral specialization for communicative behaviors, this question has been overlooked in the literature, largely because *handedness* has traditionally referred to manual asymmetries for non-communicative object-directed activities. It has been shown that the direction of handedness for manipulative actions is not a good indicator of hemispheric dominance for speech (e.g., Knecht et al., 2000), yet it is only relatively recently that researchers have started to differentiate communicative gestures from manipulative activities in the study of hand preferences. Embracing again both ontogenetic and phylogenetic perspectives, I thus aimed at examining the development of hand preference for gestures to shed light on the mechanisms that underlie speech–gestures links, in relation to the left-hemisphere specialization for language processing.

The first chapter of this dissertation provides the theoretical background relevant to the issues of language development and hand preference, along with the research questions addressed in the present work. The next chapters present six articles, including first a literature review focusing on pointing gestures. This literature review is followed by a presentation of the methodology used and by experimental papers that investigated the relationship between hand preferences and speech in children and adults.

CHAPTER 1. Language development and hand preferences

1.1. Language and communicative gestures

1.1.1. Communication, language and speech

Some misunderstanding and controversy in the literature usually flow from the use of core concepts that are not clearly defined, *language* being the prime example. First and foremost, the content of concepts central to the present work such as communication, language and speech therefore needs to be clarified.

Communication refers to the numerous means through which a specific message is conveyed from a signaller to one or several receivers (Alcock, 2005). All animals have a communication system, whose degree of complexity varies from the simple use of chemical cues to a combination of various modalities including olfactory signals, visual displays and vocalizations of different types (e.g., Zahavi & Zahavi, 1997). Human communication is probably the most complex system in the animal kingdom, notably involving facial expressions, gestures, laughter, crying, music and language. Moreover, it is important to distinguish the general concept of communication from *intentional communication*, which involves different mechanisms. Rather than being just triggered by specific environmental conditions, intentional communicative signals are used flexibly and deliberately (e.g., Tomasello & Moll, 2010). Several behavioral criteria have been described in humans to characterize intentional communication. First, the production of a signal relies on the presence of a social partner and is likely to be repeated or adjusted if the recipient's reaction reveals an apparent failure in communication (e.g., Bates, Camaioni, & Volterra, 1975). Second, actual intention to communicate a message to a specific recipient is associated with attention-getting and visual orienting behaviors from the signaller (e.g., Leavens, Russell, & Hopkins, 2005).

Language is thus one of the forms of intentional communication available to humans, defined as a learned symbolic system, infinitely flexible, allowing individuals to express a variety of meanings about the past, present, and future. Language is characterized by multiple components and even includes, in its broadest sense, communicative gestures (e.g., McNeill, 2005). Although most of gestures – distinct from signs produced in sign languages – are learned signals subject to cultural variations (e.g., Wilkins, 2003), they will not be regarded as a component of language *per se* in the definition adopted in the present work. Language will refer to the ability to use abstract symbols, mostly words, through a set of rules shared by the communicative partners. Viewed from this angle, language represents and communicates thoughts, ideas and emotions in a more precise and flexible way than gestures or any other systems (Fitch, 2010). Lastly, *speech* is used in a more narrow sense to describe one of the ways in which language can be expressed, by using the vocal-auditory mode to convey information.

In humans, communicative skills start to develop in the first few months of life within interactive processes with caregivers. By developing fundamental abilities such as gaze following and turn-taking, infants become able to actively engage with partners in shared attention (e.g., Carpenter, Nagell, & Tomasello, 1998; Heimann et al., 2006), which is a central prerequisite of language acquisition (e.g., Tomasello, 1999). A large number of studies have investigated the development of language, focusing on its different components, namely phonology, morphology, syntax, semantics, prosody and pragmatics (e.g., Halliday, 2003). Here I will study language acquisition in children between approximately 1 and 3 years of age, mainly through the development of lexical and syntactic abilities. Moreover, language learning is not a linear process, which led me to focus on key milestones such as the lexical spurt period (see Chapter 5).

1.1.2. Communicative gestures

Communicative gestures can be divided into quite a few functional categories, within which they can be described on the basis of several features including hand shape, orientation of the hand, movement and position in the gesture space (e.g., Kendon, 2004). The classification of gestures is usually based on the nature of the relationship between the gesture and its referent, in relation to semiotics and the *icon / index / symbol* triad, originally developed by Peirce (1960). Icons have specific properties in common with their objects, for example similarity in shape; indexes are directly connected to and influenced by their objects; and symbols have an arbitrary and convention-based relationship with their objects. More specifically, and though the terminology used to describe the same gestures varies across researchers (see Guidetti & Nicoladis, 2008), the study of communicative gestures usually involves the distinction between deictic gestures (corresponding to Peirce's *index* category) and representational gestures (e.g., Crais, Day-Douglas, & Cox-Campbell, 2004; Liszkowski, 2008). The category of representational gestures includes both iconic and symbolic gestures, the former being based on similarity (e.g., describing the size or movement of objects with the hands) and the latter on conventionality or habit (e.g., nodding the head, waving "goodbye"). Although gesture classification illustrates the diversity of gestures, a shift from categories to dimensions has been suggested to be more appropriate to illustrate the multiple facets of gestures, especially for co-speech gestures produced by adults (see McNeill, 2005). The interest in gestures accompanying speech, also referred to as "gesticulations", can be traced back to Roman antiquity (Kendon, 2007) and they continue to be extensively studied (e.g., McNeill, 1992). However, I will focus here on communicative gestures produced by children as language develops, gestures that are therefore not comparable to adults' co-speech gestures.

Infants express themselves from an early stage through nonverbal communicative behaviors such as gazes, babbling, vocalizations, facial expressions and postures, but it is the production of gestures that marks the onset of intentional communication properly speaking, from approximately 12 months of age (e.g., Tomasello, Carpenter, & Liszkowski, 2007). As indicated by cultural differences observed in the form, the frequency and the context of use of gestures (e.g., Iverson, Capirci, Volterra, & Goldin-Meadow, 2008; Kendon & Versante, 2003), the cultural and social environment plays a key role in the development of gestural communication. However, communicative gestures seem to emerge in children of all cultures, and to emerge without any explicit training. Factors common across different cultures may thus explain the development of gestural communication. In addition to a prolonged period of locomotor immaturity (see Leavens, Hopkins, & Bard, 2005 for a discussion on the referential problem space), human infants experience numerous interactions with caregivers in the course of development. These two factors lead to various situations in which communicative gestures prove to be an efficient means before the emergence of speech for achieving specific goals, which are not exclusively tied to physical needs (e.g., Guidetti, 2003).

Children’s gestures are usually classified according to the nature of these goals, a commonly-used distinction contrasting imperative with declarative intentions. Imperative gestures were first described as the use of adults as a means of obtaining an object (Bates et al., 1975), but now also include request for specific actions (Colonnesi, Rieffe, Koops, & Perucchini, 2008; Tomasello et al., 2007). For example, in the first case, children produce imperative pointing gesture in order to obtain a biscuit which is out-of-reach on the table, and in the second case, they raise their arms to request being picked up by the adult. Declarative gestures, first described as the use of an object as a means of obtaining adult attention (Bates et al., 1975), currently involve the aim of sharing interest in a specific referent with the adult (e.g., Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). More recently, another communicative function has been highlighted: informative gestures, which were initially described as a subtype of declarative gestures (Tomasello et al., 2007) are used by children to provide the recipient with information he/she needs about a referent (Liszkowski, Carpenter, & Tomasello, 2008).

The degree of complexity and the early forms of psychological understanding associated with infants'communicative gestures have given rise to much debate. While some researchers have claimed that the production of gestures, from 12 months of age, involves an understanding of the intentions, attention, and knowledge of the communicative partner (see Liszkowski, 2011), others have emphasized the instrumental nature of infants' gestures (e.g., Leavens & Racine, 2009; Moore & Corkum, 1994). According to this latter view, imperative gestures, used to obtain a material reward, and declarative gestures, used to obtain a social and emotional reward, are associated with simple learning processes rather than with high-level cognitive and social abilities. Offering an alternative to the "lean" versus "rich" interpretations, some researchers have argued that infants' communicative gestures may reveal an intentional reading of behaviors that does not necessarily rely on representations of unobservable mental states (Gómez, 2007), or only involve social-cognitive understanding from approximately 18 months of age (D'Entremont & Seamans, 2007).

Pointing gesture, which is used to draw someone's attention to a specific external referent, has received particular attention in the present work (see Chapter 2). The categorization of pointing has been debated, but researchers usually classify it is as a deictic gesture. Indeed, the relationship between the pointing gesture and its referent depends on the respective localizations of the signaller, the recipient of the signal and the item indicated. In opposition to symbolic reference which is based on an arbitrary relationship between the signal and its referent (e.g., Camaioni, 2001), pointing has thus been identified as nonverbal reference (Leavens et al., 2005). Pointing allows children to enlarge their communicative repertoire and express meanings that cannot yet be expressed verbally, raising the question of the speech–gesture links and the role played by gestures in the development of communicative skills.

1.1.3. Speech–gesture links

The influence of gestures on both the gesturer and the observer has been the subject of intensive investigations in the last decades. In adults, gestures that accompany speech enhance communication by helping to disambiguate the speaker's message. The perception of these co-speech gestures, activating cerebral regions associated with the processing of semantic information (Dick, Goldin-Meadow, Hasson, Skipper, & Small, 2009), therefore facilitates discourse comprehension. In infants, the perception of gestures may also provide a communicative framework that facilitates comprehension by directing more easily their attention. Thus, children at two and four years of age rely more heavily on adults' pointing gestures than on verbal information to identify objects (Grassmann & Tomasello, 2010).

Gestures also influence the gesturer him or herself, as revealed by studies showing that the production of gestures enhances performance in spatial visualization tasks (Chu & Kita, 2011) or in problem solving-tasks such as the Tower of Hanoi (Goldin-Meadow & Beilock, 2010). Allowing individuals to lighten cognitive load and change mental representations, gestures thus seem to facilitate learning processes (Goldin-Meadow, 2006), including language learning. Through gestures, children can express and explore ideas of increasing complexity, which may indeed contribute to cognitive change in the representation and understanding of other people's mental states and help children acquire the complex skills of intention-reading (e.g., Moll, & Tomasello, 2007; Vallotton & Ayoub, 2010). These abilities play an important role in the building of communicative abilities and in language development.

Moreover, communicative gestures produced by infants and children may facilitate language acquisition by shaping their social and linguistic environment. Gestures enhance interactions with communicative partners and elicit verbal responses that illustrate the appropriate lexicon and grammatical constructions in a specific situation (e.g., Goldin-

Meadow, Goodrich, Sauer, & Iverson, 2007; Kishimoto, Shizawa, Yasuda, Hinobayashi, & Minami, 2007; Vallotton, 2009). For example, correlations reported between the age of onset of gesture-word combinations and the age of onset of two-word utterances suggest that caregivers' verbal commentaries following children's gesture-word combinations may help the latter make the transition to two-word speech (e.g., Capirci, Iverson, Pizzuto, & Volterra, 1996; Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005).

To sum up, the predictive relationship between gestures used by infants and toddlers and later language development (e.g., Colonnesi, Stams, Koster, & Noom, 2010; Rowe & Goldin-Meadow, 2009) relies on a facilitative relationship based on both direct and indirect mechanisms, the former referring to the development of sociocognitive abilities and the latter to the influence of gestures on adults' responses.

Given the multiple dimensions of communicative gestures, researchers have investigated whether the relationship between gestures and language development was specific to one category of gestures, and/or to one communicative function. Although symbolic gestures have been argued to facilitate the early stages of language acquisition (e.g., Goodwyn, Acredolo, & Brown, 2000), changes in children's gestural repertoire during development suggest that pointing gestures play a paramount role in language acquisition. The frequency of pointing gestures, produced in combination with words or vocalizations, has been reported to increase during the second year of life (e.g., Guidetti, 2002; Özçaliskan & Goldin-Meadow, 2005), whereas the use of symbolic gestures decreases as speech develops (e.g., Acredolo & Goodwyn, 1988; Rodrigo et al., 2006). Pointing gestures appear thus to play a supportive role in different milestones of language acquisition, from the establishment of joint attention to the ability to combine several words (Goldin-Meadow, 2007).

However, the nature of the speech–gesture links may differ according to the function served by the pointing gesture. The production of declarative pointing has been reported to be more closely related to social-cognitive understanding than imperative gestures (Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004), and therefore more likely to play a role in the emergence of speech. Moreover, the study of behavioral markers such as hand shapes, hand preference and vocalizations, illustrating the distinction between imperative and declarative gestures (see Chapter 4), suggests that the two types of gestures emerge from distinct processes. Imperative gestures have been hypothesized to develop from non-communicative reaching actions through a process of ontogenetic ritualization (Tomasello & Call, 1997), while the development of declarative gestures may rely more on early social-cognitive abilities, including imitation. This hypothesis, which will be investigated further throughout the present dissertation, implies that the relationship between gestures and language development involves declarative gestures rather than imperative ones.

1.2. Study of hand preferences

A large part of the present work is concerned with the study of manual asymmetries associated with children's communicative gestures, with the aim of further supporting the existence of speech-gesture links. Studies of hand preference originally pertained to object-directed actions and currently, *handedness* mainly refers to non-communicative manipulative activities. Therefore, even if there is no explicit agreement on this issue among researchers, I will preferentially use the term *hand preference* to describe the asymmetry of communicative gestures so as to avoid any confusion. As the next chapters will highlight, these different terminologies are also associated with distinct developmental trajectories.

1.2.1. Manipulative activities

A right-sided bias in hand-use patterns for manipulative activities is observed in the vast majority of humans. Although the proportion of right-handed individuals seems to remain relatively constant around the 90% mark (e.g., Annett, 1985; Raymond & Pontier, 2004), this proportion varies from approximately 70 to 90% (e.g., Dragovic & Hammond, 2007; Perelle & Ehrman, 1994), depending on the methods used to assess handedness and to classify individuals into categories. Handedness is indeed characterized by multiple dimensions, leading to some discrepancies between studies (e.g., Healey, Liederman, & Geschwind, 1986). A first point of confusion is the use of distinct handedness categories, which is not always based on statistical analyses, whereas this variable is distributed continuously. This categorization can involve a simple dichotomy between right-handers and left-handers, but researchers usually define several categories to reflect different degrees of handedness and consider the lack of consistent preferences. Mixed-handedness patterns can be represented by more than one category though (e.g., Annett, 1970), thus limiting comparability between studies.

A second issue pertains to the variety of methods and tasks used to collect handedness data. Handedness can be assessed through self-reported questionnaires referring to daily activities or through direct observation of hand use in tasks requiring participants to perform either functional (e.g., hammering) or arbitrary activities (e.g., peg-moving tasks). These different methods lead to a distinction between preference and performance measures of handedness, which have been argued to reflect different dimensions of manual asymmetries (e.g., Brown, Roy, Rohr, Snider, & Bryden, 2004). Moreover, the use of unimanual versus bimanual tasks may also influence handedness patterns. Bimanual coordination activities, in which the dominant hand plays an active role and the non-dominant hand a role of support or orientation, have been reported to elicit a greater degree of handedness than unimanual activities (e.g., Fagard, 2004).

In addition to these methodological issues, the question of the origins of handedness remains largely unanswered, although it seems that both genetic (e.g., Annett, 1985) and environmental factors come into play (e.g., Fagard & Dahmen, 2004; Vuoksimaa, Koskenvuo, Rose, & Kaprio, 2009). Some authors have suggested that pre-natal lateralized motor behaviors, such as thumb sucking and head position, influence the subsequent development of handedness (e.g., Hepper, Wells, & Lynch, 2005; Ververs, de Vries, van Geijn, & Hopkins, 1994). However, the development of handedness, which is associated with a considerable degree of intra- and inter-individual variability, seems to involve more complex processes. Although signs of right-sided asymmetries in object manipulation are manifest early in infancy (see Provins, 1992), the degree of handedness has been reported to fluctuate during the first years of life (e.g., Ferre, Babik, & Michel, 2010), which might reflect successive reorganizations of the motor system (e.g., Corbetta & Thelen, 1999). The strength of manual asymmetry was shown to stabilize only at around 7 years of age (McManus et al., 1988).

1.2.2. Communicative gestures

Few data are available regarding manual asymmetries of communicative gestures, compared to the abundant literature on handedness for manipulative actions. A right-sided bias has been observed for gestures accompanying speech in adult speakers (e.g., Dalby, Gibson, Grossi, & Schneider, 1980; Kimura, 1973; Saucier & Elias, 2001), as well as for signing in deaf people (e.g., Bellugi, 1991; Vaid, Bellugi, & Poizner, 1989). Several studies with infants and children have also reported an asymmetry in favor of the right hand for symbolic gestures and deictic gestures such as pointing (e.g., Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Blake, O'Rourke, & Borzellino, 1994; Vauclair & Imbault, 2009; Young, Lock, & Service, 1985). These developmental studies have concluded that the right-sided bias for pointing is established in the early stages of development, as it did not seem to vary between approximately 1 and 3 years of age. However, the study by Vauclair and Imbault (2009) involved a cross-sectional design and in Bates et al.'s longitudinal study (1986), children were observed at 13, 20 and 28 months of age. These studies therefore may not be perfectly suitable for identifying developmental changes in hand preference, and the other studies mentioned did not assess hand preference beyond 15 months of age (Blake et al., 1994; Young et al., 1985). Longitudinal studies with short sampling intervals are thus needed to investigate further the development of asymmetries for communicative gestures.

A growing body of research has explored the relationship between hand preferences for communicative and non-communicative activities, revealing greater right-sided asymmetry for pointing gestures than for object manipulation (Bates et al., 1986; Jacquet, Esseily, Rider, & Fagard, 2011; Vauclair & Imbault, 2009). A study of children born to deaf parents using sign language has also reported a greater degree of hand preference for signed gestures than for other manual activities (Bonvillian, Richards, & Dooley, 1997). Moreover, hand preferences for pointing gestures and manipulative actions appear not to be significantly correlated in young children (Esseily, Jacquet, & Fagard, 2011; Jacquet et al., 2011).

Although the right-sided asymmetries observed for both communicative and non-communicative activities indicate a stronger involvement of the left cerebral hemisphere, the existence of different patterns of hand preference for gestures and object manipulations has to be considered when investigating the relationship between hand preference and language.

1.2.3. Insights into cerebral processes: relation between hand preference and language

In the vast majority of human individuals, the main language functions are controlled by the left cerebral hemisphere, involving neural networks in which Broca's and Wernicke's areas play a key role in the production and the comprehension of language, respectively. Some researchers have argued that language dominance was significantly related to handedness for manipulative activities because language processing is more frequently lateralized to the left cerebral hemisphere in right-handers than in left-handers (Knecht et al., 2000). However, this relationship is far from being direct since a majority of left-handed individuals do not have right-hemisphere dominance for language (e.g., Króliczak, Piper, & Frey, 2011). In fact, using an event-related imaging technique, Knecht et al. (2000) have shown that language processing is lateralized to the left cerebral hemisphere in more than 95% of right-handers, but also in 70% of left-handers. Thus, handedness for manipulative activities does not appear to be a reliable indicator of hemispheric language dominance. As manipulative activities and communicative gestures are associated with different patterns of hand preference, we may expect to observe different percentages by focusing on the asymmetry of communicative gestures. Moreover, considering the speech–gesture links described above, it can be hypothesized that hand preference for gestures is a more relevant and significant functional marker of hemispheric specialization for language than handedness for object manipulation.

In human adults, behavioral and neuroimaging studies tend to support this hypothesis. Using a dichotic listening task and examining the asymmetry of co-speech gestures, Kimura (1973) observed a right-ear superiority for speech processing in nearly 90% of right-handers and a left-ear superiority in two-third of left-handers. Although this study involved relatively few participants, it revealed a significant relationship between the asymmetry of gestures and cerebral dominance for speech. The close interconnection between speech and gesture has also been emphasized by studies demonstrating the influence of gestures on voice parameters (e.g., Krahmer & Swerts, 2007). Bernardis and Gentilucci (2006) showed that the voice frequency spectrum increases when a word and the corresponding gesture are produced simultaneously, compared to conditions involving only the production of words, or involving both modalities but meaningless arm movements and pseudo-words. Moreover, imaging studies have revealed that the perception of speech and communicative gestures (symbolic and iconic gestures) activates common networks in left-lateralized inferior frontal and posterior temporal regions (e.g., Willems, Özyürek, & Hagoort, 2007; Xu, Gannon, Emmorey, Smith, & Braun, 2009). There is also neural evidence that semantic information conveyed through speech and gestures are integrated simultaneously by the brain (Özyürek, Willems, Kita, & Hagoort, 2007).

The study of sign language offers further support to the existence of speech–gestures links. In addition to the left hemisphere superiority reported in deaf people for sign language processing (e.g., Grossi, Semenza, Corazza, & Volterra, 1996), functional brain imaging studies have shown that the production of signs activates regions similar to those implicated in spoken language use, including Broca’s area (e.g., Corina, San Jose-Robertson, Guillemin, High, & Braun, 2003; Emmorey, Mehta, & Grabowski, 2007). A left hemisphere advantage in processing linguistic information has also been observed in deaf children exposed to cued speech, which is a visual mode of communication that uses handshapes in combination with the mouth movements of speech to represent the phonemes of a spoken language. Deaf participants and hearing controls were shown to display comparable left hemisphere specialization for semantic processing of written language (D’Hondt & Leybaert, 2003) and similar accuracy of phonological representations (Leybaert, 2000), suggesting that semantic and phonological abilities develop independently of the modality (acoustic versus visual) through which language is perceived.

Altogether, these results suggest that a specific system in the left cerebral hemisphere, specialized in linking meaning with symbols, controls both gestural and vocal communication (e.g., Gentilucci & Dalla Volta, 2008). However, within the framework of action-grounded cognition theory (see Anderson, 2003), the relationship between right-handedness and left-hemispheric brain specialization for language has been suggested to involve action in general rather than being restricted to communicative gestures. According to this view, the relation between language and gesture is one particular form of the relation between language and action (e.g., Willems & Hagoort, 2007). Neurophysiological data showing that the size of a grasped object influences lip opening kinematics and voice parameters, and neuroanatomical data reporting the existence of neurons controlling grasping movements both of hand and mouth tend to support this interpretation (see Gentilucci & Dalla Volta, 2007, for a review). Nonetheless, findings of most studies examining this issue indicate that complex processes may underlie the relationship between language, action, and gesture, which therefore still deserves thorough investigation. For example, Gonzalez and Goodale (2009) have shown that language lateralization was related to hand preference for precision grasping, but the correlation explained only 15% of the variance, and no other measure of handedness for manipulative activities was found to be related to language lateralization.

To determine the exact nature of the relationship between language and hand preference, researchers have also focused on the development of communication and speech acquisition in infants and children. Neuro-cognitive bases of language development seem to develop very early. Infants and toddlers present functional and structural hemispheric asymmetries in speech perception-production networks (e.g., Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002; Dubois et al., 2009; Mills, Coffey-Corina, & Neville, 1993), although hemispheric specialization for language continue to increase during childhood (e.g., Ressel, Wilke, Lidzba, Lutzenberger, & Krägeloh-Mann, 2008). Moreover, some studies have highlighted an early association between the cerebral control of speech and communicative gestures. Using event-related potentials during a priming task, a study reported N400 congruency effect for pictures preceded by both words and gestures in 18-month-old infants, demonstrating that words and gestures elicit similar patterns of semantic activation (Sheehan, Namy, & Mills, 2007). Furthermore, a study with infants between 11 and 13 months of age has shown that the production of request gestures towards large objects rather than small objects leads to an increase in the acoustic properties (F2 formant) of the infants' vocalizations (Bernardis, Bello, Pettenati, Stefanini, & Gentilucci, 2008). This effect on the vocal spectra was also observed when infants manipulated the objects, revealing, as in adults, the existence of complex relationships between the control of speech, gestures and actions. However, as previously described, communicative gestures and manipulative actions are associated with different patterns of hand preference in children. Thus, although language and action may not develop independently, results of infant studies suggest that the bimodal communication system in the left cerebral hemisphere may differ from the system involved in purely motor activities (e.g., Vauclair & Imbault, 2009).

1.3. Phylogenetic and ontogenetic perspectives

The relationship between gestures and speech acquisition during human ontogeny raises intriguing questions about the role played by gestures in the evolution of language. Speech–gesture links could be explained in the light of the gestural hypothesis for the origin of language (e.g., Hewes, 1973; Corballis, 2009, 2010; Vauclair, 2004). According to this hypothesis, gestures constituted the first intentional means of communication for early Hominids. Lateralization of speech evolved from this left-lateralized gestural system and, in the course of evolution, the vocal modality gradually became dominant (e.g., Gentilucci & Corballis, 2006). By contrast, the evolutionary precursors of human language have been claimed to lie in vocalizations (vocal hypothesis, e.g., Lemasson, 2011) or in a combination of gestural and vocal signals (bimodal hypothesis, e.g., Masataka, 2008).

Although researchers lack direct evidence about the origins and evolution of language, this issue can be insightfully studied by examining communicative behaviors in our nearest primate relatives. Nonhuman primates possess a considerable species-specific repertoire of gestures, used to communicate with conspecifics in various situations such as greeting, invitation for grooming, food-begging, or threat (e.g., Hobaiter & Byrne, 2011; see Pika, Liebal, Call, & Tomasello, 2005, for a review). More specifically, chimpanzees have been reported to produce pointing gestures in specific physical and social environments. Thus, confronted with the referential problem space (Leavens et al., 2005), captive individuals for example use imperative gestures directed to human partners in order to be given food. Moreover, chimpanzees that experience close relationships with humans, mainly language-trained and home-raised individuals, also produce pointing gestures serving functions other than the imperative function (e.g., Leavens & Bard, 2011). Although apes' spontaneous pointing gestures, especially declarative pointing, seem to be exceedingly rare in the wild (e.g., Veà & Sabater-Pi, 1998), these results highlight some continuities between the communicative gestures produced by nonhuman primates and human language, including intentionality, flexibility of use, and referential properties (see Meguerditchian & Vauclair, 2008; Pika, 2008, for reviews).

In addition, studying the asymmetries associated with nonhuman primates' gestural communication may improve our understanding of the origin of human left-hemisphere specialization for language. Population-level right-hand preference has been reported for a variety of communicative gestures, namely human-directed food begging gestures (e.g., Hopkins & Wesley, 2002) and intra-species gestures used in different social contexts such as the "extended arm" and the "hand slap" (e.g., Meguerditchian & Vauclair, 2006). By contrast, although some individuals developed a preferential use of one hand over the other, several studies failed to show any population-level handedness for unimanual reaching (e.g., Meguerditchian, Calcutt, Lonsdorf, Ross, & Hopkins, 2010; Vauclair, Meguerditchian, & Hopkins, 2005). Population-level handedness is evident in great apes for coordinated bimanual activities (e.g., Hopkins et al., 2011), but these manipulative actions elicit lower degrees of right-sided asymmetry than communicative behaviors and hand preferences for communicative gestures and non-communicative actions were shown not to be significantly correlated (e.g., Meguerditchian & Vauclair, 2009; Meguerditchian, Vauclair, & Hopkins, 2010).

Moreover, neuroanatomical data collected in chimpanzees have revealed a significant relation between the right-sided bias for communicative gestures and leftward asymmetries in the inferior frontal gyrus (Taglialatela, Cantalupo, & Hopkins, 2006). Handedness for reaching actions was not associated with any neuroanatomical asymmetries in this cerebral region regarded as the homologous of Broca's area, thus supporting the prominent role of gestures in the evolution of language and its hemispheric lateralization.

Although the comparison of ontogenetic and phylogenetic processes involved in the development of speech–gestures links requires some caution, it can be hypothesized that communicative gestures have played a role in shaping communicative skills in the course of Hominin evolution, through the development of both social and cognitive abilities. Increasing use of gestures, possibly with the gradual incorporation of vocalizations (e.g., Corballis, 2003), may have fostered social interactions among conspecifics and allowed individuals to develop some abilities to represent and influence another person's attentional state, driven by the selective advantages of more and more complex joint attention skills. In line with this hypothesis, the production of communicative gestures in our species has been argued to be associated with unique cognitive abilities reflecting human evolutionary adaptation for symbolic reference (e.g., Tomasello, Carpenter, Call, Behne, & Moll, 2005).

From a neurobiological point of view, the mirror-neuron system, which has been assigned a key role in understanding others' intentional actions, may constitute the substrate from which complex forms of communication evolved (e.g., Fogassi & Ferrari, 2007). These neurons, first discovered in the premotor cortex of macaques (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), discharge both during the execution of a hand or mouth action and during the observation of the similar action performed by another individual. Thus, by matching a gesture produced by a communicative partner with one's own internal motor representations, the observer may attribute a meaning to a specific gesture, leading eventually to the emergence of intention-reading abilities and to the acquisition of language (e.g., Corballis, 2010).

1.4. Aims of the present thesis

The state of art reviewed in this chapter shows that plenty of studies have focused on the development of communicative gestures in young children as well as on the relationship between gestures use and language acquisition. Gestural communication, through the different forms and functions it encompasses, allows infants to interact with communicative partners in various situations and appears to be closely related to the emergence of speech.

Moreover, researchers have long investigated manual asymmetries, seeking to identify the processes involved in functional hemispheric specialization. Both speech processing and hand preference are associated with left-hemisphere superiority in humans, but few studies have examined these issues simultaneously. Besides, these studies have provided only partial answers regarding the relationship between language and hand preference, possibly because they mostly focused on hand preference for non-communicative manipulative actions rather than for communicative gestures.

Bringing together the two areas of research mentioned above, the present work sought to investigate the production of communicative gestures during development with particular attention to the study of hand preference, in order to clarify the nature of speech–gestures links. A first objective is to describe infants' and toddlers' gestures, notably in terms of communicative functions, hand shapes, accompanying vocalizations and gaze behavior. A second objective is to use the development of hand preference for communicative gestures as an index, although indirect, of the cerebral processes involved in communication. Observational and experimental studies have been conducted to provide some insights into the role played by communicative gestures in language development, in relation to early forms of social and cognitive abilities, and to identify the characteristics of gestures that are particularly involved in the emergence of speech–gestures links. More specifically, considering the clear distinction that is usually made between imperative and declarative gestures, I aimed to determine to what extent communicative functions influence the relationship between gestural communication and language acquisition.

Although most of the studies presented in the following chapters focused on infant development, a study was also carried out on adults to examine the continuity between hand-preference patterns associated with children's and adults' communicative gestures, in comparison with handedness for manipulative activities. Moreover, as language and strong degree of right-handedness have both been regarded as hallmarks of the human species, this dissertation made a point of embracing both ontogenetic and phylogenetic perspectives on the mechanisms that underlie speech-gesture links. Thus, developmental patterns observed in human infants may parallel the evolution of language at the phylogenetic level, in relation to the emergence of hand preference and brain lateralization. Because language has historically occupied an outstanding position in enlightening human nature, the issue of language origins is of central importance to understanding the evolutionary roots of human social cognition and communication.

To put it in a nutshell, the purpose of the present dissertation is to provide significant data regarding the complex processes of language acquisition in children, including the mechanisms of cerebral specialization for communicative behaviors, by adopting also a broader approach pertaining to the evolutionary origins of language.

CHAPTER 2. A focus on pointing gestures

2.1. Introduction

Research on communicative gestures in children has largely focused on pointing because this is the most frequent gesture produced by toddlers and children from approximately 1 year of age (e.g., Butterworth & Morissette, 1996; Rodrigo et al., 2006; Stefanini, Bello, Caselli, Iverson, & Volterra, 2009) and because it can also be easily elicited in experimental contexts (e.g., Liszkowski et al., 2004). Pointing can be described as a communicative movement that projects a vector from a body part (Kita, 2003) in order to indicate a specific referent in the proximal or distal environment. It can thus involve the mouth and the eyes (see Enfield, 2001 and Wilkins, 2003 for examples in adult populations), although the present work studied exclusively manual pointing. The latter is elicited in a variety of situations and is characterized by several features (e.g., hand shape, accompanying vocalizations, gaze, and hand preference). Taking these multiple dimensions into account may reveal some insights into the exact nature of the intentions underlying children's pointing gestures.

Moreover, pointing gesture has been viewed as a "unique milestone in children's linguistic and social development" (Colonnesi et al., 2010, p. 363), but we still need to determine to what extent the various functions and various forms of pointing are interlinked with facets of speech acquisition. With this in mind, the following article provides a description of recent research on pointing and the development of speech–gesture links in infancy. In a first section, we discuss several studies of the different functions and hand shapes of pointing gestures and examine evidence for pointing having different origins and playing different roles in the emergence of speech depending on their function. In a second section, we explore the links between manual activities and language, looking at the development of hand preference for pointing gestures and manipulative actions.

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Pointing gesture in young children:

Hand preference and language development

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Abstract

This paper provides an overview of recent studies that have investigated the development of pointing behaviors in infants and toddlers. First, we focus on deictic gestures and their role in language development, taking into account the different hand shapes and the different functions of pointing, and examining the cognitive abilities that may or may not be associated with the production of pointing gestures. Second, we try to demonstrate that when a distinction is made between pointing gestures and manipulative activities, the study of children's hand preference can help to highlight the development of speech–gesture links.

Keywords: toddlers, gestural communication, pointing, handedness, speech–gesture system.

Emergence of communicative gestures: Focus on pointing gestures

Pointing is a specialized gesture for indicating an object, event or location. Children start using pointing gestures at around 11 months of age (Butterworth & Morissette, 1996; Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004), and this behavior opens the door to the development of intentional communication. One of the prerequisites for the production of pointing gestures is a shared experience between the signaler and the recipient of the gesture, that is, a simultaneous engagement with the same external referent, usually referred to as *joint attention* (e.g., Carpenter, Nagell, & Tomasello, 1998). While pointing is sometimes regarded as a “private gesture” (Delgado, Gómez, & Sarriá, 2009), whose main role is to regulate the infant’s attention rather than to enable the latter to communicate with a recipient, a growing body of research suggests that the onset of pointing gestures reflects a newly acquired ability to actively direct the adult’s attention to outside entities in triadic interactions (e.g., Liszkowski, 2005; Tomasello, Carpenter, & Liszkowski, 2007).

Before describing some of the main physical features of pointing, we discuss the different communicative functions associated with pointing gestures, and the different social and cognitive skills they may or may not reflect.

Different communicative intentions

Several criteria are commonly used to characterize a gesture as intentional: (1) the behavior of the signaler has to be produced and directed toward a recipient, (2) the gesture is usually accompanied by visual-orienting behaviors, including gaze alternation between the recipient and the object or event being pointed at (this visual monitoring enables signalers to check the efficiency of the gestures, thus confirming their communicative intention), and (3) children are likely to repeat their gesture if they fail to produce the desired effect on their communicative partner (this persistence of the signal is also interpreted as a demonstration of intentionality). Researchers currently seem to agree over the intentional nature of the pointing gesture, but the latter encompasses different communicative functions that need to be examined if we are to see the whole picture.

In order to determine an infant’s intention when he or she points toward a referent, researchers take several criteria into account. They focus on the accompanying features of the child’s gesture (vocalizations, facial expressions, posture), the adult’s behavioral reaction to the child’s gesture, and the child’s behavior following the adult’s first reaction (see example below).On the basis of these different clues, they can generally distinguish between the two main functions of pointing gestures, named the imperative and declarative functions (e.g., Camaioni, 1997; Tomasello et al., 2007). Children use imperative gestures to obtain something from the adult, whether it is a specific action or a desired object. Declarative pointing gestures direct the adult’s attention to a referent in order to indicate its existence and share interest in it. More specifically, according to Tomasello, Carpenter, and Liszkowski (2007), in *declarative expressive* pointing, children seek to point out some object, location or event to the adult that they consider interesting and worthwhile, while in *declarative informative* pointing, they seek to provide the adult with information he or she needs.

In some cases, it can be difficult to distinguish between the imperative and declarative motives behind children's pointing gestures. Most of the time, children's imperative gestures serve to request an object -indeed, these communicative behaviors are sometimes referred to as "request" gestures or "ritualized reaches" (e.g., Franco & Butterworth, 1996; Iverson & Goldin-Meadow, 2005), but imperative pointing can also be used to ask an adult to do something with an object (e.g., Colonnesi, Rieffe, Koops, & Perucchini, 2008). Thus, when an adult makes something interesting happen, such as activating a mechanical toy, how should children's pointing be interpreted? Are they trying to share interest in the event with the adult or are they asking the adult to make that event happen again? The request behaviors that sometimes accompany children's gestures (e.g., whining, leaning forward, displaying negative affect) may help answer this question. Moreover, infants are very likely to display signs of dissatisfaction and repeat their pointing gesture if they do not achieve their goal the first time around. In the above example, if the child seems dissatisfied when the adult comments on the event of interest and does not activate the mechanical toy again, one can infer that the infant's motive was indeed imperative.

Above and beyond the different imperative and declarative motives behind children's gestures, the question naturally arises as to the nature of the cognitive abilities associated with these pointing gestures.

Cognitive abilities and pointing

The issue of the social and cognitive abilities involved in the use of pointing gestures has long been debated. Some authors support an instrumental reading of pointing, arguing that it develops through processes close to operant conditioning and that infants are simply seeking to obtain an object or a positive emotional reaction to the self from the adult (e.g., Bates, Camaioni, & Volterra, 1975; Moore & Corkum, 1994). By contrast, pointing is sometimes viewed as a cognitively complex gesture, reflecting infants' understanding of others' attention. Even when they are still in the early stages of development, children appear to be able to make references to external events or objects, and even to absent entities (Liszkowski, Schäfer, Carpenter, & Tomasello, 2009).

A parallel is sometimes drawn between these different theoretical accounts and the different functions of pointing. Basically, a rich mentalistic interpretation of declarative gestures, in which infants try to influence others' mental states, can be contrasted with a lean interpretation of imperative gestures, in which they try to influence others' behavior. There are several pieces of evidence supporting the dissociation between imperative and declarative gestures. Firstly, in development, the comprehension and production of imperative gestures precedes that of declarative gestures (Camaioni et al., 2004; Cochet & Vauclair, 2010-a). Moreover, gestures produced by children with autism seem to lack the declarative function (Camaioni, 1997; Camaioni, Perucchini, Muratori, & Milone, 1997), leading to the idea that imperative and declarative gestures may rely upon different cognitive abilities. The production of communicative gestures in nonhuman primates also tends to support the distinction between imperative and declarative functions (e.g., Leavens, Hopkins, & Bard, 1996). There have been very few reports of declarative gestures in apes, and they concerned individuals that had experienced close emotional ties with humans and/or had been language-trained (see Leavens, 2009). It has therefore been argued that rearing history and emotional bonding with caregivers may play a role in the ability to develop declarative communication.

Adults' reactions can be experimentally manipulated in order to investigate the communicative intention and cognitive abilities involved in the production of infants' pointing. Adopting this approach, an experimenter reacted to 12-month-olds' pointing toward an interesting event in different ways (Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). When the adult emoted positively toward the child without looking at the event, the infant showed signs of dissatisfaction, pointing less often across trials and repeating points more within trials. By contrast, infants were satisfied in the joint attention condition, that is, when the experimenter reacted to the event being pointed at and shared interest with the child. These results revealed that infants wanted the adult to integrate a specific referent into the interaction and share interest about it. In declarative situations, infants therefore expect more than just the other's attention and a display of interest toward them, contrasting with the instrumental view of pointing (e.g., Moore & Corkum, 1994). Experimental studies have highlighted the complexity of the social and cognitive skills involved in the production of declarative gestures (e.g., Liszkowski, 2005). For example, it has been shown that the ability to use declarative pointing is linked to the understanding of the other person's intentions, whereas this relation is not observed for imperative gestures (Camaioni et al., 2004).

However, the distinction between rich and lean interpretations of pointing gestures, depending on their functions, has been questioned by several researchers, who have proposed other alternatives. Leavens (2009) disproves the strict distinction between imperative and declarative pointing, arguing that every pointing gesture serves an instrumental function, at least in the early stages. According to him, infants seek to elicit specific affective behaviors from their caregivers rather than to share interest with adults about a referent. Consequently, declarative pointing would not demand higher cognitive abilities than imperative pointing. Moore and D'Entremont (2001) also argue that early declarative pointing is motivated egocentrically, representing attempts to receive a positive reaction to the self from the adult. The main evidence for this interpretation is that 12-month-olds point to events that the adult is already looking at. However, as previously exposed, these findings can be interpreted differently, children's intention being likely to elicit a reaction from the adult indicative of shared attention and interest (Liszkowski et al., 2004).

In the same vein, and though these statements still need further experimental investigations to be considered as clear empirical evidence, Southgate, van Maanen, and Csibra (2007) regard the pointing gesture as an interrogative act in all contexts: children point in order to obtain information about an object or event. Pointing would not imply a cooperative motive -sharing interest or helping another person would not be an end in itself-, but rather a selfish need to learn about the environment. It has also been suggested that declarative pointing reflects the child's interest in the referent (the object or event being pointed at), without necessarily implying any involvement with the adult (Colonnesi et al., 2008).

Moreover, according to Tomasello, Carpenter, and Liszkowski (2007), imperative motives form a continuum from ordering to suggesting. In the former, the adult is understood to be a causal agent from whom the child can obtain what he/she wants, whereas the motive involved in the latter is less individualistic and more cooperative: the adult is regarded as an intentional agent who can decide whether or not to help the child.

Cochet and Vauclair (2010-b) have suggested that declarative expressive pointing may play an intermediate role in the development of communicative skills. They compared toddlers' communicative behaviors (pointing gestures, hand shapes, gaze patterns and accompanying vocalizations) in imperative, informative and expressive situations (Tomasello et al., 2007). Results revealed an opposition between imperative and declarative (both expressive and informative) gestures in relation to accompanying vocalizations–the latter were more frequent in the declarative situation than in the imperative one–, and also regarding hand shape, in that declarative gestures were mostly characterized by index-finger pointing, whereas imperative gestures were more frequently produced with the whole hand (see following section). However, their findings also highlighted a difference between informative pointing and the two other types of gestures with regard to hand preference (see the section concerning manual preference) and gaze pattern. Gaze alternation was more frequently coordinated with pointing in the informative situation, indicating that children were more likely to monitor the adult's attention to the external referent in this cooperative context. Declarative expressive pointing was therefore closer to imperative pointing, regarding visual behavior and hand preference, but closer to declarative informative pointing, regarding vocalizations and hand shapes, hence the hypothesis that expressive pointing represents an intermediate stage between imperative and informative communication (Cochet & Vauclair, 2010-b).

To briefly summarize, the distinction between imperative and declarative functions on the basis of cognitive differences is increasingly being called into question. It seems rather that various parameters come into the picture, including affective factors. Interestingly, we may also have to look again at the assumption of a causal relation between the development of cognitive skills and the production of pointing gestures, in favor of the hypothesis of mutual influence over development. Nonetheless, the psychological abilities that pointing may or may not reflect constitute a tricky issue for researchers. Hypothetical mental processes have to be inferred from behavioral measures, as the cognitive processing involved in the production of pointing gestures cannot be directly measured. On the basis of these behavioral measures, we believe that there are at the very least motivational differences between imperative, declarative expressive and declarative informative pointing gestures.

Different hand shapes for pointing

Pointing gesture has traditionally referred to its canonical form: extended index finger and all other fingers tightly retracted (e.g., Blake, O'Rourke, & Borzellino, 1994; Butterworth, Franco, McKenzie, Graupner, & Todd, 2002; O'Neill, Bard, Linnell, & Fluck, 2005) and though index-finger pointing is the most commonly observed morphology, comparative investigations of pointing gestures have revealed cultural variations in hand shapes and in the degree of orientation of the forearm (prone versus supine position). Forms encountered in some cultures are very rarely produced by English speakers, for example when the middle finger, not the index finger, is pointed toward a target (Wilkins, 2003). This is the reason why the narrow definition of pointing is usually replaced by a broader one that includes different hand shapes (e.g., Brooks & Meltzoff, 2008; Gullberg, de Bot, & Volterra, 2008; Krause & Fouts, 1997). Few studies have focused on the forms of pointing, but researchers mostly distinguished between whole-hand and index-finger pointing (Cochet & Vauclair, 2010-a, 2010-b; Leavens & Hokpins, 1999). The term “whole-hand pointing” was initially used in studies with nonhuman primates, as the latter rarely produce index-finger gestures. In human children, too, at least until the age of three years, the extension of the index finger does not seem to be a key feature of the pointing gesture. A study comparing the efficacy of various forms of pointing in an object-choice task (Lakatos, Soproni, Dóka, & Miklósi, 2009) showed that two-year-old children relied on the direction of the protruding body part, rather than on the direction of the index finger, to find a hidden toy. Three-year-old children, however, understood the meaning of the index finger and were also able to generalize from familiar pointing gestures to unfamiliar ones (e.g., pointing with the knee).

In addition to the cultural differences previously exposed, it seems that hand shapes are influenced by discourse context. Thus, on the basis of recordings made in natural situations, Kendon and Versante (2003) identified instances of pointing produced by Neapolitans, in order to investigate whether hand shapes differed according to the communicative context. These authors observed that conventional index-finger pointing (palm-down position) was more likely to be produced when the gesture was semantically important to the ongoing discourse, whereas pointing gestures with all the fingers extended seemed to convey the notion of nonsingularity or nonindividuation. Moreover, pointing can be performed with different parts of the body, such as the hand, the mouth or the eyes, depending, for example, on the visibility of the referent or the formality of the context (Wilkins, 2003).

The morphology of pointing gestures thus appears to be influenced by cultural and contextual factors and it is reasonable to assume that the use of one particular hand shape rather than another involves some degree of social transmission. This hypothesis is supported by the difference observed in the morphology of pointing gestures between sighted and blind toddlers. Sighted children have been reported to use index-finger pointings most frequently and whole-hand pointings rarely, whereas blind children, who have not been confronted with the model of index-finger pointing, produced a vast majority of whole-hand pointings (Iverson, Tencer, Lany, & Goldin-Meadow, 2000).

Moreover, the distinction between different functions of pointing gestures has revealed an age-related increase in index-finger pointing at the expense of whole-hand pointing for declarative gestures, but not for imperative ones (Cochet & Vauclair, 2010-b). In an imperative situation, children kept on using whole-hand pointing, even though they were able to produce index-finger pointing, indicating that the distinction between hand shapes in infancy may depend on the context of use, as in adulthood, although the functions of the pointing gestures produced by children and adults remain different.

Origins of pointing gestures

The different functions and physical features of pointing gestures have theoretical implications regarding their origins, both at the ontogenetic and phylogenetic levels. In imperative pointing, the child uses the adult as a means of obtaining a desired object (e.g., Bates et al., 1975). The key determinant of this gesture is the inability to obtain the object by oneself, whether because of immature motor abilities in the case of human infants or because of captivity conditions in the case of nonhuman primates (Bard, 1990; Leavens, Hopkins, & Bard, 1996, 2005). Imperative pointing is thus rather self-centered and related mostly to the action of reaching toward an object. Consequently, and though there might be some alternatives to this hypothesis (see Carpendale & Lewis, 2006), it has been suggested that this gesture gains a communicative motive through social scaffolding, in a process known as *ontogenetic ritualization* (Tomasello & Call, 1997). This process enables a manual action to become progressively ritualized into a social and communicative gesture, on the basis of the adult's reactions to this specific action. Vygotsky (1988) had previously argued that all pointing gestures develop out of failed reaching, and though consistent with the imperative function of pointing, this hypothesis does not seem well-grounded with regard to declarative pointing.

It has been suggested that declarative gestures may be learned through social imitation during children's development, rather than being ritualized from reaching actions (Cochet & Vauclair, 2010-a, 2010-b). This hypothesis is supported by studies of nonhuman primates, as the production of declarative pointing has only been observed in chimpanzees that have experienced close relationships with humans (Leavens, 2009), and that were thus given the opportunity to imitate humans' communicative behaviors. However, further empirical investigations in human infants are needed to confirm the role of imitative abilities in the development of declarative pointing.

As there is no direct evidence of the learning processes through which the different kinds of pointing are acquired, researchers mostly have to base their arguments on behavioral cues. For example, the difference in hand shapes between imperative and declarative gestures supports the hypothesis of different origins for these pointing gestures. Imperative pointing is mostly characterized by whole-hand gestures whereas declarative pointing is more frequently produced with an extended index finger (Cochet & Vauclair, 2010-b). Moreover, these authors have found that the form of imperative gestures remains unchanged between 15 and 30 months of age, highlighting the close relationship between the structural characteristics of reaching actions and imperative pointing, even once children are able to produce index-finger pointing.

The different origins of imperative and declarative pointing gestures may also be reflected in different degrees of relationship with language development, as set out in the following section.

Relations with language development

Various studies have shown that gestures and speech are closely related in humans (Bates & Dick, 2002; Iverson & Thelen, 1999). This interconnection can be observed in people's natural conversation, as gestures frequently accompany discourse (Goldin-Meadow, 2003; McNeill, 1992). These co-speech gestures lend rhythm, emphasize speech and sometimes serve an iconic function, and although they have no direct linguistic function, they make the speaker's message easier to understand. A study using event-related potentials yielded neural evidence that both modalities are simultaneously integrated by the brain in order to understand an utterance (Özyürek, Willems, Kita, & Hagoort, 2007). Moreover, functional brain imaging studies have revealed that symbolic gestures and spoken words are processed by a common network of inferior frontal and posterior temporal regions of the left hemisphere (Xu, Gannon, Emmorey, Smith, & Braun, 2009) and that sign language activates Broca's area in the left hemisphere (e.g., Corina, San Jose-Robertson, Guillemin, High, & Braun, 2003; Emmorey, Mehta, & Grabowski, 2007). These results suggest that these areas, rather than being restricted to speech processing, have a modality-independent role in linking meaning with symbols.

The dynamic interplay between speech and gestures can be observed from the early stages of development onward. For instance, a study revealed that the emergence of babbling at around seven months of age is accompanied by an increase in repetitive right-handed activity (Locke, Bekken, McMinn-Larson, & Wein, 1995). More generally, gestural communication, notably pointing, provides a foundation for verbal communication, both predicting and facilitating the acquisition of language (e.g., Capirci & Volterra, 2008; Pizzuto & Capobianco, 2005; Rowe & Goldin-Meadow, 2009; Rowe, Özçaliskan, & Goldin-Meadow, 2008). The ability to combine two ideas in a single utterance first manifests itself in gesture-word combinations and the latter are thought to reflect a transitional stage in development, in that the age of onset of supplementary gesture-word combinations is correlated with that of two-word combinations (Ozçalişkan & Goldin-Meadow, 2005).

Recent findings suggest that the facilitative role of gestures in language acquisition may concern declarative but not imperative gestures. According to Camaioni and colleagues (2004), the use of declarative pointing is linked to the understanding of adults' intentions and is associated with the development of theory of mind abilities. These abilities are necessary for the emergence of speech, making declarative pointing gestures likely prerequisites for the development of human language. Other researchers also argue that some features of human language, namely social cognition and cooperation, are already reflected in toddlers' declarative pointing (Liszkowski et al., 2004; Liszkowski, Carpenter, Striano, & Tomasello, 2006; Liszkowski, Carpenter, & Tomasello, 2008). Moreover, when Cochet and Vauclair (2010-a) recorded pointing gestures produced by toddlers in spontaneous interactions at a daycare center, they found that declarative gestures were more frequently accompanied by vocalizations than imperative gestures were (Cochet & Vauclair, 2010-a), suggesting that these two types of pointing have different relationships with the vocal system.

In order to further investigate the links between gestures and the emergence of language, the second section of this review is devoted to the development of manual asymmetries.

Handedness and language development

Identifying lateralized patterns of communicative gestures is an indirect means of studying hemispheric lateralization for the control of these gestures (Kimura, 1973-a, 1973-b). Asymmetry in favor of the right or left hand suggests the functional dominance of the contralateral cerebral hemisphere, and given the left-hemispheric specialization for language functions observed in the majority of humans (Knecht et al., 2000), studying the asymmetries associated with gestural communication may allow researchers to bring a new perspective on the relationship between gestures and language.

Studies investigating handedness have traditionally focused on manipulative actions, possibly because the notion of hand preference is so salient when talking about object manipulation. There are indeed many occasions in daily life when we can observe asymmetrical manipulation in the use of tools, whereas laterality for communicative gestures is less perceptible. People usually notice when the person next to them is writing with his/her left hand, but they rarely pay attention to the hand used by somebody pointing toward an object or event of interest. Laterality for communicative gestures is also more difficult to assess than handedness for manipulative actions, which is mostly measured through hand preference questionnaires. For these reasons, handedness in gestural communication has tended to be disregarded. However, in recent years, interest in the development of communicative gestures has grown considerably. Researchers have then started investigating asymmetries in the production of these gestures, especially at the time of language emergence.

Manual preference for pointing gestures

Several studies have reported a right-hand bias for pointing gestures in infants and toddlers (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Blake, O'Rourke, & Borzellino, 1994; Cochet & Vauclair, 2010-a, 2010-b; Young, Lock, & Service, 1985). Although the spatial location of the referent influences hand choice for pointing, children are more likely to point to locations within their left visual field with their right hand than to locations in their right visual field with their left hand (Butterworth et al., 2002; Esseily, Jacquet, & Fagard, in press). Asymmetries in favor of the left hemisphere also apply to the *perception* of pointing gestures. It has been shown that pointing is understood significantly earlier for targets in the infant's right visual field than for ones in the left visual field (e.g., Carpenter et al., 1998).

In the course of development, the right-sided asymmetry for pointing gestures has been found to increase during the child's first twelve months of life (Blake et al., 1994). However, several researchers have failed to observe any increase in this right-handed bias between approximately one and three years of age (Bates et al., 1986; Cochet & Vauclair, 2010-a, 2010-b). The development of hand preference for gestures may vary according to factors other than age.

With this in mind, Vauclair and Cochet (submitted) set out to investigate the relationship between handedness for pointing gestures and lateralization for language. They measured hand preference for pointing in 46 toddlers aged 12-30 months and assessed their language level on the revised Brunet-Lézine scale (Josse, 1997), which allowed them to calculate a developmental quotient for language. Pointing gestures were found to be more right-handed in children with a high developmental quotient, namely in children who seemed to have higher learning abilities, compared to children with average language quotients. Event-related potential studies have previously reported a relation between increasing level of speech abilities and increasing involvement of the left cerebral hemisphere (Mills, Coffey-Corina, & Neville, 1993). According to Vauclair and Cochet (submitted), the fact that the latter is associated with a stronger right-handed bias for pointing gestures suggests the existence of a bimodal system in the left cerebral hemisphere, controlling both gestural and vocal communication.

Manipulative activities versus pointing gestures

Research on right-handedness and language, as stated above, initially focused on manipulative actions. It found that 96% of right-handers and 70% of left-handers had left-hemispheric control for speech (Knecht et al., 2000), indicating that the relationship between handedness for manipulation and speech is, at best, indirect. In order to find out whether hand preference for pointing gestures is a better marker of hemispheric lateralization for language, we need to know the proportion of right-handed people for pointing gestures who present left-hemisphere specialization for language, and in turn, the proportion of left-handed people who are right-hemisphere dominant. Studies by Kimura (1973-a, 1973-b) have come closer to this issue, revealing a significant relationship between the cerebral dominance for speech (assessed with a dichotic listening task) and manual asymmetry. However, they focused on free movements that accompany speech, letting the question regarding intentionally produced pointing gestures still unanswered.

A more workable solution for investigating the relationship between the cerebral control of speech and pointing gesture is to compare patterns of manual preference between pointing gestures and manipulative activities. Researchers have reported a stronger degree of manual asymmetry for pointing gestures than for object manipulation (Bates et al., 1986; Cochet & Vauclair, 2010-b; Vauclair & Imbault, 2009). Moreover, in the study by Vauclair and Imbault (2009) with 123 infants and toddlers aged 10-40 months, a large proportion of the children who were left-handed or ambidextrous for object manipulation pointed with their right hand, whereas very few right-handers shifted to the left hand for pointing. The stronger involvement of the left hemisphere for pointing gestures supports the view that speech and gestures form an interconnected system, distinct from the system that is involved in purely motor activities. In nonhuman primates, communicative behaviors also show a stronger degree of population-level right-handedness than manipulative actions (e.g., Hopkins et al., 2005; Meguerditchian & Vauclair, 2009; Meguerditchian, Vauclair, & Hopkins, 2010), which can be interpreted within an evolutionary framework about the origin of speech. The greater activation of the left hemisphere for communicative gestures in our closest cousins suggests that this left-lateralized gestural–vocal system may have a deep phylogenetic origin (Corballis, 2010; Meguerditchian, Vauclair & Hopkins, 2010).

The distinction between the different functions of pointing has yielded some interesting results regarding hand preference patterns. In an experimental study, three situations in day nurseries were designed to elicit imperative, declarative expressive and declarative informative pointing gestures (see above, page 130) in 48 toddlers (Cochet & Vauclair, 2010-b). A unimanual reaching task was also administered. The difference in the degree of manual preference between manipulative actions and pointing gestures was found to be strongest for informative pointing. The latter is produced to provide the adult with information he or she needs about a referent and may thus involve cooperation abilities (Tomasello et al., 2007). This result suggests that the development of cooperation, notably through the production of informative pointing, may play a role in the cerebral lateralization of human communicative behaviors. Bullinger, Zimmermann, Kaminski, and Tomasello (2010) have emphasized the especially cooperative nature of human communication, comparing the production of pointing gesture between chimpanzees and human infants. They observed that the chimpanzees pointed only when it was to their ultimate benefit, whereas 25 month-old infants pointed no matter who benefited. The authors have thus suggested that the informative motive, both at the ontogenetic and phylogenetic levels, may play and have played an important role in the emergence of linguistic communication.

To summarize the question of handedness, Figure 1 presents the results of four studies carried out in our laboratory, illustrating the need to distinguish (1) between manipulative activities and pointing gestures, and (2) between the different functions of pointing. This figure also emphasizes that research on the relationship between handedness and language development is made more difficult by methodological differences between studies. Gestures can include different communicative functions and hand preference can be assessed in either naturalistic or experimental situations. Regarding manipulation, handedness can be measured either through self-reported questionnaires or through direct observation of hand use, and using either unimanual or bimanual tasks. These different measures may lead to different patterns of handedness being recorded, as the degree of hand preference has been shown to vary according to task complexity (Fagard & Marks, 2000). Finally, handedness indices are not consistently used -some researchers only consider the total numbers of right- and left-handed gestures that are produced- and the distinction between right- and left-handers is not always based on the same criteria across studies. While some researchers define an *a priori* hand preference threshold, without any statistical criterion (e.g., participants are categorized as right-handed if the handedness index is above 0.5), others rely on statistical tests to classify individuals as right- or left-handed (see Hopkins, 1999).

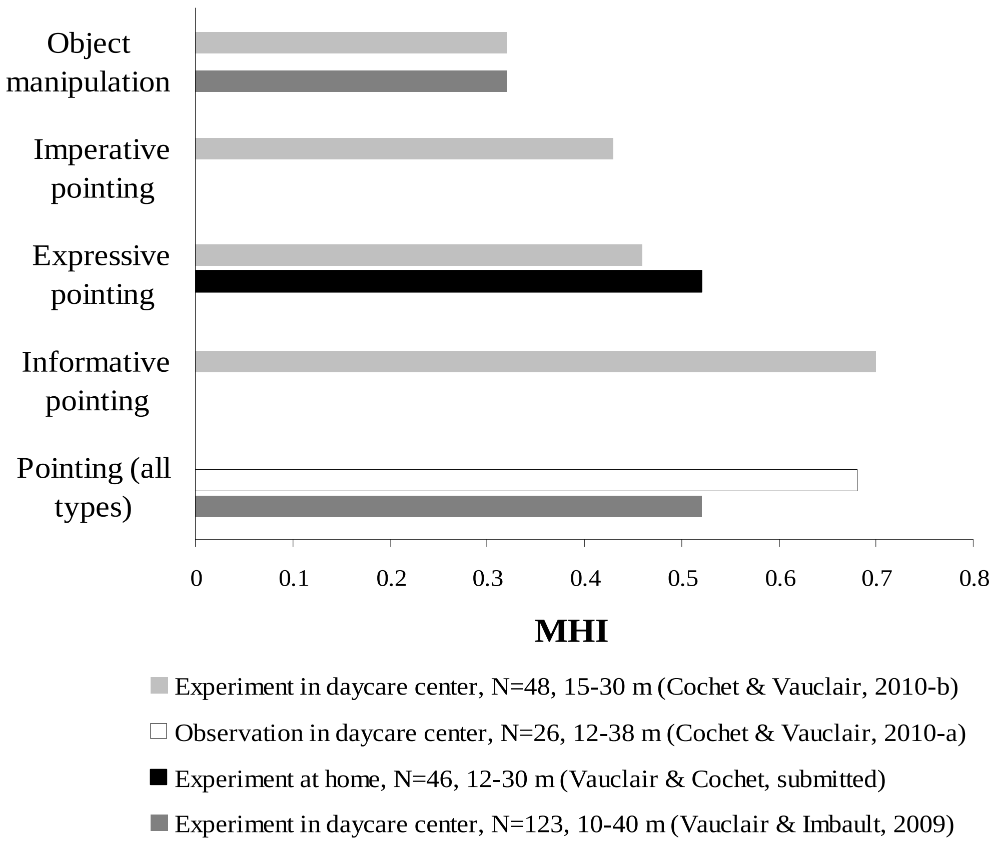

Figure 1. Mean handedness indices (MHI) associated with object manipulation and pointing gestures in different studies. Handedness index traditionally varies from -1 to 1. The positive sign here reflects right-hand preference and the absolute values the strength of hand preference.

Manipulative activities, pointing gestures and language

Pointing gestures and manipulative activities present different patterns of hand preference, but a right-handed bias is observed for both activities. Gestural communication and object manipulation are therefore both lateralized to the left cerebral hemisphere, albeit to different degrees. The control of actions, gestures and language may thus involve complex, intertwined networks, rather than independent development. From the motor theory of speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967) to the more recent discovery of the mirror neuron system (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992), the relationship between motor control and language has long been the focus of research.

The contiguous representations of hand and mouth in the cerebral cortex constituted one of the first arguments supporting the role of the motor system in the emergence of speech. More recently, researchers described seven stages in the evolution of language, emphasizing the key role of the motor system (Roy & Arbib, 2005). For these authors, articulated language evolved from grasping movements. These praxic movements then became adapted for communicative purposes and, with the parallel development of the vocal apparatus, protospeech emerged and gradually coevolved with protosign, leading to the emergence of the final stage: speech. In support of this scenario, Gonzales and Goodale (2009) demonstrated a positive correlation in adults between hand preference for precision grasping and language lateralization (measured by a dichotic listening test). However, the correlation they observed was moderate, which may imply that other processes come into play.

Moreover, if pointing gestures and speech do indeed originate from object manipulation, then how can we explain the different patterns of handedness observed between pointing gestures and manipulative actions (Bates et al., 1986; Vauclair & Imbault, 2009)? A longitudinal study investigating the relationship between language, manipulative actions and pointing gestures in 25 toddlers may go some way toward answering this question (Cochet, Jover, & Vauclair, submitted). Participants were observed once a month in day nurseries over a five-month period. Handedness was measured both with manipulative tasks and communicative tasks, including imperative and declarative pointing, and language level was assessed through a parental questionnaire. Measures of handedness for declarative pointing gestures were not correlated with those of handedness for manipulation, but the results revealed a significant correlation between hand preference for imperative pointing gestures and manipulative activities prior to the vocabulary spurt. Once the latter had occurred, this correlation became nonsignificant. This study illustrates the complex relationship between handedness and language development and underscores the need to take the different functions of pointing gestures into account.

Another study showed that handedness for manipulative actions significantly correlated with handedness for pointing gestures between 18 and 20 months and between 29 and 32 months, whereas correlations were not significant in the interim (Vauclair & Imbault, 2009). According to the authors, these two key phases, corresponding to the onset of the vocabulary spurt and the improvement in syntax, generate a specific cognitive load in the left hemisphere. The development of handedness in relation to language acquisition therefore seems to involve complex interactions between manipulation and communication, but it is difficult to interpret these findings further, especially as language level was not directly measured in this study.

Pointing gestures and manipulative actions may share several properties that would explain the close interconnection in the brain between the control of manual action and language processing (e.g., Gentilucci & Dalla Volta, 2007; Willems & Hagoort, 2007). Both activities involve visuomotor control and the understanding of behaviors as being connected to targets through attention. Furthermore, it has been suggested that the lateralization of visuomotor control to the left hemisphere precedes the emergence of left specialization for praxis and language (Gonzales & Goodale, 2009). Moreover, manipulative and communicative activities may be both associated, albeit to different extents, with the development of an intentional and representational system that is also required for the control of articulate speech. Kendon (2009) for example argued that the emergence of language has been made possible through the transformation of praxic activity into “communicative actions”, pointing and pantomiming. In this regard, the representational properties of the mirror neuron system may play a major role. These neurons, first discovered through single cell recordings in the ventral premotor cortex (area F5) of macaques (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), which fire during both the execution and the observation of actions, have been assigned a role in understanding others’ intentional actions. Furthermore, it has been suggested that the role of the mirror neuron system evolved from the understanding of transitive actions to the understanding of intentional communication in humans (e.g., Capirci & Volterra, 2008). The mirror system may thus be the ideal neural substrate for the emergence of theory of mind and language (e.g., Fadiga & Craighero, 2007; Gentilucci & Dalla Volta, 2008; Rizzolatti & Arbib, 1998).

Conclusion

The different studies described in this review highlight the role played by gestural communication, especially pointing gestures, in the control of intentional and referential communication. We present a number of arguments, some drawn from our own studies, in favor of the notion that pointing gestures are part of a broader and multimodal communicative system. We go on to demonstrate the relevance of studying hand preference for pointing gestures in order to fully investigate the development of communicative behaviors and improve current understanding of the nature of speech–gesture links. One consequence arising from this perspective is the need to distinguish between object manipulation and pointing gestures, as the degree of handedness may differ between these two activities. Lastly, we point out the complex relationship between actions, gestures and language in the course of development and emphasize that studies of pointing gestures should take several dimensions (e.g., functions, hand shapes, accompanying vocalizations) into account in order to pinpoint these multifaceted interconnections.

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Conclusion

There is general agreement that the production of pointing gestures is closely linked to the development of linguistic abilities. As shown by a meta-analysis of the relationship between pointing gestures and language development (Colonnesi et al., 2010), children's early gesture use not only precedes, but also contributes to speech acquisition through both direct and indirect mechanisms (see Chapter 1). However, some studies did not reveal any significant relationship between pointing gestures and language abilities (e.g., Bates et al., 1986; Colonnesi et al., 2008), suggesting that some features may moderate this relationship. Some of these features may relate to different communicative contexts, according to which characteristics of pointing gestures are likely to vary. Therefore, in order to identify these moderating features, we need to investigate thoroughly the production of pointing gestures in children. Such an investigation requires that the methods used be clearly defined *a priori*.

CHAPTER 3. General methods

To investigate the relationship between gestural communication and language development, cross-sectional and longitudinal studies have been conducted with toddlers and adults, involving both observations and experiments in different settings. This chapter provides an overview of the participants who took part in the different studies presented in the following chapters, as well as a description of the procedures and measures that were used.

3.1. Child studies

3.1.1. Participants

Children were recruited from the surrounding area with the help of paediatricians and day-care centers personnel. Parents were informed about the goals of the different studies and their written consent was granted before the observation of the children. French was the native language of all participants. Children were observed in their second and third year of life, a developmental period during which communicative gestures are broadly used and speech experiences a remarkable development. This age range thus appeared as the most appropriate period to describe developmental changes in communicative behaviors. The exact age ranges as well as the number of participants in each study are displayed in Table 1.

Table 1. Summary of the number and age of participants in the different child studies.

Study	Number of participants	Age range
Article II	26	11.5 - 37.8 months
Article III	48	14.6 - 31 months
Article IV	8	15 - 25 months
Article V	25	13 - 21 months

3.1.2. Description of the different procedures

Different methods of data collection were used, including first observation in a naturalistic context (article II). Spontaneous gesturing of young children was observed in a day-care center, in a natural context of interactions with adults and other children. The main objective was to provide an overview of pointing in a sample covering a wide age range, by taking into account several features such as the communicative function of the gestures, hand shape and hand preference.

Second, experimental studies were carried out to study the different functions of pointing gestures (article III) and investigate the relationship between the production of pointing and language level (article IV and V). Conditions of experiments were thus pre-arranged, including the objects and toys used as target referents of pointing, the prompts given to the children, the reactions of the experimenter and the number and duration of trials. Experimental designs therefore allowed us to gain control over the eliciting context and facilitated the data collection related to hand preferences, since we could control for the effect of positional bias on hand use (i.e., we controlled the respective positions of the experimenter and of the different targets with regard to the child). Moreover, experimental studies allowed us to assess children’s language level using a standardized scale (the revised Brunet-Lézine scale, see below), which required being administered in a consistent manner across children.

It is important to note that both observational and experimental studies were conducted in natural settings, namely in places that were familiar to the children, either in their day-care center or at home. We thus intended to overcome the over-reliance on artificial laboratory contexts in studies of children’s communicative behaviors. In addition, in each study, children were allowed to familiarize themselves with the experimenter and become accustomed to the situations during “warm-up” periods that preceded the data collection.

In day-care centers, children were observed in isolation in a separate room, or when this was not possible, in the main room but apart from the other children. As for studies conducted at the children's home, children were tested in the room where they were most used to play, either in the child's bedroom or in the living-room. Mothers were present during the entire session but they were instructed not to initiate interactions with their child, especially for the language test, and not to point toward the different targets during testing in order not to influence the child's responses. Video recordings were made in each study to assess interobserver reliability.

The present work included two longitudinal studies conducted over periods of five and ten months, and two cross-sectional studies. In the first longitudinal study (article IV), carried out at home, children were tested on six successive occasions at bimonthly intervals between 15 and 25 months of age. In the second longitudinal study (article V), carried out in day-care centers, children were tested at monthly intervals on five successive occasions, during the second year of life. In the latter study, all the participants did not start the testing at the same age, due to some difficulties in recruiting a sufficient number of participants. Children were thus between 13 and 17 months of age at the first session. Cross-sectional studies allowed us to collect data from larger samples. Table 2 summarizes the different methods, settings and designs used in each study.

Table 2. Summary of the different procedures used in child studies.

Study	Method	Setting	Design
Article II	observation	day-care center	cross-sectional
Article III	experiment	day-care centers	cross-sectional
Article IV	experiment	home	longitudinal
Article V	experiment	day-care centers	longitudinal

3.2. Adult study

The last study that will be presented (article VI) involved adult participants, recruited among students of the University of Provence on a voluntary basis. The purpose of this study was to elicit pointing gestures and bimanual manipulative activities in natural and plausible contexts, in order to compare the degree of hand preference between these different activities. Participants were tested individually in an experimental room of the university and were contacted again by e-mail at the end of all the experiments so that we could collect additional measures of hand preference through a self-reported questionnaire.

3.3. Description of the different measures

3.3.1. Language level

Language level was assessed with two different language tests, each having their own drawbacks and advantages. First, in a longitudinal study (article V), parents were asked to fill in a questionnaire based on the French adaptation (Kern, 2003) of the MacArthur Communicative Development Inventories (MCDI; Fenson et al., 1993). Parents had to indicate the words their child was able to produce within a list of 691 words, split into 22 categories (see Appendix 1). The language score corresponded to the total number of words the children had in their vocabulary, which allowed us to determine when children's productive vocabulary reached 50 words, a stage that has been associated with the onset of the vocabulary spurt (e.g., Goldfield & Reznick, 1990; Nazzi & Bertoncini, 2003, and see Chapter 5). Although the original MacArthur test includes both comprehension and production scales, only production was taken into consideration in the proposed questionnaire, for several reasons. First, we assumed that the assessment of word production might be less subject to parental subjectivity than the assessment of word comprehension, as the latter relies on indirect indices (e.g., the child's behavioral reaction to a specific question or instruction).

Moreover, completing the production scale required some time and patience from the parents, especially as they were asked to fill in the questionnaire every month, and adding a comprehension scale may have been too demanding.

The second language test used to measure children's language level was the "language" sub-test of the French Brunet-Lézine scale (1965), revised by Josse (1997). This scale, designed for infants and toddlers between 2 and 30 months of age, assessed both language comprehension and production through several tasks involving familiar objects and pictures (see Appendix 2). Depending on their age, children either have to indicate the location of the object or picture designated by the experimenter, among several ones, or they directly named them. Other items are based on parental reports, but most of the time, the experimenter also had the opportunity to observe the target behavior during the session (for example, items assessed the child's ability to produce two-word utterances). Parental reports were thus mainly used to corroborate the experimenter's observations. A raw score is obtained, from which it is possible to infer a developmental age for language via the available French norms. Dividing the developmental age by the chronological age yields a developmental quotient for language. This test, through direct observation of children's responses in standardized tasks, may provide a less subjective measure of language level than the use of parental questionnaire. However, the score obtained does not enable the distinction between language comprehension and production, nor between lexical and syntactic skills.

3.3.2. Hand preferences

Examining hand preferences requires several precautions so that the measures carried out reflect effective manual asymmetry inherent in each person, rather than the influence of external factors such as the individual's posture and the position of the different objects and referents in space. First, in order to avoid postural biases, data on hand preferences for both communicative gestures and manipulative actions were only recorded when children were seated in a symmetrical position, with both hands initially free. Second, the objects and stimuli used in the experimental studies were positioned on the child's sagittal midline in order to cancel out the effect of target location (e.g., Butterworth, Franco, McKenzie, Graupner, & Todd, 2002) and the experimenter was seated in front of the participants. In the observational study, data were only collected when the referents were positioned centrally in front of the children.

In each study, hand preference was assessed for the different tasks using an individual handedness index score (HI), calculated with the formula $(R - L) / (R + L)$, where R and L stood for the total right- and left-hand responses. The HI values lay along a continuum from –1 to 1, with the sign indicating the direction of hand preference (a positive sign reflecting right-hand preference) and the absolute value (AbsHI) characterizing the strength of hand preference. The number of observations used to measure hand preference is usually limited in studies with infants and toddlers, as it is obviously difficult to maintain their attention and interest over a long period of time, in particular when several tasks are administered. For example, researchers investigating hand preference in toddlers administered 5 trials in different pointing tasks (e.g., Vauclair & Imbault, 2009) and classified children as left-handed, right-handed or non-lateralized in different manipulation tasks on the basis of 2 responses (Fagard & Marks, 2000). In the present work, we chose not to calculate handedness indexes when children produced only 1 response (i.e., only 1 gesture or only 1 manipulative action) and we ensured that handedness scores for manipulative actions and pointing gestures were based on a comparable number of responses to allow a valid comparison between these different activities. Moreover, mean handedness indexes were used to characterize hand preference within groups of participants.

In addition to handedness indexes, which are widely used in studies on hand preference with human children and nonhuman primates (e.g., Chapelain, Bec, & Blois-Heulin, 2006; Esseily et al., 2011; Vauclair & Imbault, 2009), we also reported in some studies (article IV and VI) the number of left-handers, right-handers and ambidextrous (or non-lateralized) individuals in the different tasks. This categorization, based on a statistical analysis of the number of left- and right-hand responses, provided additional information to compare communicative gestures and manipulative activities, allowing us to determine whether the classification of participants was consistent across the different tasks.

3.3.3. Communicative gestures

In the present work, communicative gestures, regarded as such provided they were produced and directed towards a recipient, have been studied in different communicative contexts. Several features associated with the production of gestures were taken into account in addition to hand preference, including the accompanying vocalizations, gaze behavior and hand shapes.

It can sometimes be difficult to determine whether children's manual movements intend to convey a specific message to a communicative partner or if they correspond to the initiation of a non-communicative action, the distinction between imperative pointing and object grasping being the prime example. The behavioral markers described in Chapter 1 thus need to be closely investigated to establish the real communicative intention associated with gestures (see also Meguerditchian, Cochet, & Vauclair, 2011). The informative clues generally used to distinguish between imperative and declarative gestures include the adult's behavioral reaction to the child's gesture and the child's behavior following the adult's first reaction to his/her point. Depending on the reaction of recipients that apparently satisfy the gesturer, the experimenter can thus determine the real function of the gesture produced. For example, in declarative pointing tasks, children were not given the toys they had pointed at and yet, they did not show any signs of dissatisfaction, indicating that their goal was not to obtain the toys, but rather to share some interest about them with the experimenter (see also Liszkowski et al., 2004). Moreover, the tasks used in experimental studies are now regarded as reliable designs for eliciting different functions of communicative gestures, in particular imperative (e.g., Liszkowski, Schäfer, Carpenter, & Tomasello, 2009), declarative expressive (e.g., Liszkowski et al., 2004) and declarative informative gestures (e.g., Liszkowski, Carpenter, Striano, & Tomasello, 2006; see also Blake et al., 1994).

In some studies (article II and III), we recorded whether children's gestures were accompanied by vocalizations. The latter consisted of any kind of vocal productions (i.e., words, pseudo-words or other speech sounds), with the exception of whining and crying. Vocalizations were considered to accompany a gesture if they were produced at the precise moment of the pointing gesture (article III) or within a two-second interval (article II).

Children's gaze direction as they produced a gesture (within a two-second interval) was also noted in these studies (article II and III). As visual orienting behaviors have been regarded as an indicator of the signaller's communicative intention (e.g., Bates et al., 1975), we aimed to identify the contexts in which gaze alternation between the target and the communicative partner was most frequently observed.

Lastly, we investigated hand shapes of gestures through the distinction between whole-hand and index-finger pointing gestures. Whole-hand pointing was defined as the extension of all fingers, without any finger clearly distinct from the others. Index-finger pointing was characterized by the extension of the index finger, the other fingers being tightly or more lightly curled (article II and III). Hand shapes were also recorded in one of the longitudinal studies (article V), but these data did not yield any significant results and were therefore not included in the article.

Inter-rater reliability, assessed from the video recordings made in each study, was found to be good to high for these different measures.

3.3.4. Manipulative activities

Handedness for manipulative actions was assessed using unimanual grasping tasks (article III), coordinated bimanual tasks (articles IV, V, VI), and/or handedness questionnaire (article VI). For bimanual tasks, the hand that played an active role was considered as the dominant hand and the one having a role of support or orientation as the non-dominant hand. This distinction between active and passive roles for the two hands has been widely used in studies with human infants or nonhuman primates, for example with the *tube* task, in which the non-dominant hand grasps a tube while the dominant hand picks up the object or food inserted in it (e.g., Hopkins et al., 2005; Vauclair & Imbault, 2009).

As manual asymmetries have been reported to vary across different manipulative activities (e.g., Fagard & Lockman, 2005), research on hand preference should ideally involve both unimanual and bimanual tasks, but increasing the duration of experiments in studies with young children often leads to a loss of attention and interest from the latter. Therefore, the choice of the manipulation task was influenced by several factors. First, as they may require more lateralized patterns of manipulation, bimanual tasks have been regarded as more reliable and more stable indicators of handedness than unimanual tasks, especially when the two hands play much differentiated roles (Fagard & Marks, 2000). For example, population-level right-handedness has been found in nonhuman primates for a bimanual task, but not for a unimanual reaching task (Vauclair et al., 2005). However, it can also be argued that simple unimanual tasks, such as reach-to-grasp movements, provide an interesting comparison with hand-preference patterns for unimanual communicative gestures such as pointing. This may be all the more relevant when considering the different functions of pointing gestures, as the production of imperative pointing has been suggested to originate from reaching actions (see Chapter 2).

Lastly, adult participants were asked to fill in a hand preference questionnaire based on the Edinburgh Handedness Inventory (Oldfield, 1971), in addition to performing bimanual coordinated tasks. This questionnaire, containing 13 items referring mostly to unimanual activities (e.g., using a toothbrush), aimed to collect additional measures of hand preference and investigate the relationship between self-reported measures and direct observation of hand preference.

CHAPTER 4. Different functions of communicative gestures

4.1. Introduction and aims of article II

While many of the first studies on speech–gesture links were based on observations under naturalistic conditions, mostly at the children's home (e.g., Bates et al., 1975; Werner & Kaplan, 1963), current experiments are generally conducted in laboratory settings to elicit gestures in different communicative contexts (e.g., Brooks & Meltzoff, 2008; Camaioni et al., 2004; Liszkowski et al., 2009). Although experimental studies enable researchers to isolate and control the variables of interest, the use of artificial situations raises the issue of the ecological validity of measurements and may thus question the strength of conclusions drawn with regard to infants' and children's use of communicative gestures. One of the first objectives of the present dissertation was therefore to provide a general picture of the production of pointing gestures in natural settings, through spontaneous interactions with familiar adults and children. Observations, conducted in an environment familiar to the children (in their day-care center), may constitute a good starting point for identifying the features of children's gestural repertoire during development. Moreover, such an overview of communicative gestures may help us to establish operational questions in an attempt to investigate speech–gesture relationships.

In sum, the main purpose of the following study was to provide a description of pointing gestures produced by young children in a naturalistic context, between approximately 1 and 3 years of age. This description includes the function of the gestures, hand shapes, the accompanying vocalizations, visual behavior and hand preference.

4.2. Article II: Cochet, H., & Vauclair, J. (2010). Features of spontaneous pointing gestures in toddlers. *Gesture, 10*(1), 86-107.

Features of spontaneous pointing gestures in toddlers

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Abstract

This study investigated the production of spontaneous pointing gestures in 26 toddlers, who were observed during free play time at day nursery. Pointing gestures and their different features (e.g., handedness, vocalizations, form and function of gesture) were recorded for a total observation time of 100 hours. Results revealed that the vast majority of pointing gestures were right-handed and accompanied by vocalizations, emphasizing the tight interconnection between speech and gesture from an early stage of development. Whole-hand gestures were more frequently used in imperative contexts, whereas index extensions were more frequently produced in declarative ones. Moreover, the use of declarative gestures and index extensions were found to increase with age. Implications concerning the origins of imperative and declarative pointing are discussed.

Keywords: spontaneous pointing gestures, toddlers, handedness, imperative versus declarative function, index-finger versus whole-hand extensions, gestural-vocal system.

Several authors have highlighted the important role played by gesture in children's early development, reporting the existence of a significant relationship between communicative gestures produced around the end of the first year and the emergence of verbal skills at a later stage (e.g., Iverson & Goldin-Meadow, 2005; Pizzuto & Capobianco, 2005; Rowe & Goldin-Meadow, 2009; Rowe, Özçaliskan, & Goldin-Meadow, 2008; Volterra, Caselli, Capirci, & Pizzuto, 2005). The comprehension and production of communicative gestures involve cognitive processes that are essential for the acquisition of language: children develop some understanding of others' mental states through their ability to direct the attention of a recipient toward external events or objects (e.g., Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). These gestures are even regarded by some authors as a first step toward the emergence of a theory of mind (e.g., Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004). In the broad range of studies dedicated to the development of communicative skills, pointing gestures have been the subject of particular interest. Studies have focused either on the above-mentioned relationship between pointing gestures and language development (e.g., Butterworth & Morissette, 1996), or on more global features associated with these gestures, such as the preference for the right hand (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Blake, O'Rourke, & Borzellino, 1994; Vauclair & Imbault, 2009; Young, Lock, & Service, 1985) and different contexts of use (e.g., Tomasello, Carpenter, & Liszkowski, 2007).

It is generally agreed that pointing is consistently accompanied by other behavioral expressions, especially vocalizations, which is regarded as one of the first signs of the tight coupling between speech and gesture. Speech–gesture links have been highlighted at both the behavioral and anatomical levels (e.g., Bates & Dick, 2002; Gentilucci & Dalla Volta, 2008; Iverson & Thelen, 1999), leading to the hypothesis that communicative gestures are generated by a bimodal communication system in the left cerebral hemisphere, rather than by the system responsible for manipulative actions. This hypothesis implies greater activation of the left hemisphere when both modalities are simultaneously engaged, resulting in a greater degree of right-handedness. Investigations of manual activity during natural conversation in adults have indeed revealed a right-hand bias when the participants are speaking, though not when they are only listening (Kimura, 1973; Saucier & Elias, 2001). The influence of vocal behavior on the degree of manual preference for communicative gestures has also been demonstrated in nonhuman primates: Hopkins and Cantero (2003) observed a greater degree of right-handedness in chimpanzees when food-begging gestures were produced along with vocalizations. The left cerebral hemisphere may thus be more highly activated when communicative gestures and vocalizations are produced simultaneously. One of our goals in the present study was to directly test this hypothesis. If the relationship between language and communicative gestures is established at a very early stage, we would expect pointing gestures in toddlers to be more right-handed when accompanied by vocalizations than gestures produced on their own.

In many developmental studies, pointing is defined as the extension of the arm and the index finger toward an object, person or event. However, this definition is regarded as too restrictive by some authors, for whom the essence of pointing lies in its function, namely the intentional attempt to direct someone's attention toward a referent. Wilkins (2003), for instance, has defined pointing as the use of some part of the body to make a deictic gestural reference, whether it is the hand, the mouth or the eyes. One definition of pointing gestures adopted by several authors includes both the index finger on its own and the full hand with all fingers extended (Brooks & Meltzoff, 2008; Gullberg, de Bot, & Volterra, 2008; Liszkowski, Carpenter, & Tomasello, 2007, 2008). References to "whole-hand pointing" are more widespread in studies of nonhuman primates, where the traditional finger extension is less frequently observed than in human primates (Leavens, Hopkins, & Bard, 1996; Leavens & Hopkins, 1998).

This broader definition of pointing gestures brings up the issue of how to distinguish between pointing and another communicative gesture, usually referred to as a "request gesture". The latter is produced in order to obtain a desired object and is generally described as an extension of the arm toward the object, sometimes with a repeated opening and closing of the hand (Capirci, Contaldo, Caselli, & Volterra, 2005; Gullberg et al., 2008). The fact that this repeated hand movement is not consistently observed for request gestures raises the question of whether there really is a difference between pointing toward an object with the whole hand in order to obtain that object and a requesting gesture. More confusing still, "request" is not the only term used to describe arm extensions toward an attractive object intended to make the adult give the child that object. Other terms found in the literature include "open-handed reaching" (Masur, 1983), "spread" (Fogel & Hannan, 1985), "ritualized reaches" (Iverson & Goldin-Meadow, 2005) and "reaching" (Franco & Butterworth, 1996). The use of the word "reaching" can cause difficulties because it conveys different meanings: it primarily refers to the act of prehension (stretching out to grasp an object within one's reach), but can sometimes imply a communicative function. As stated above, children produce reaching gestures in order to obtain an out-of-reach object. Some authors have made a distinction between "reaching-in gestures" and "reaching-out gestures" (Blake et al., 1994). The former, which are similar to grasping, do not involve any communicative intention, unlike reaching-out gestures. In the study by Blake et al. (1994), the latter were right-handed in 8- and 12-month-old children, whereas reaching-in gestures were not. They were also accompanied by vocalizations more often than reaching-in gestures. These results emphasize the communicative nature of "reach-outs", as well as their equivalence with request gestures. It would therefore be helpful for researchers to arrive at an agreement about the accurate definition of communicative gestures, first by disambiguating the use of "reaching gestures" and then, more generally, by using the same terms to refer to the same behaviors.

For this to happen, the functions of pointing must systematically be taken into account when studying gestural communication. Two main functions of pointing gestures have been described so far (Bates, Camaioni, & Volterra, 1975; Camaioni, 1997). *Imperative* pointing is used by children to formulate a request, whereas the purpose of *declarative* pointing is to share an interest in an object or event with someone. The latter has recently been divided into "expressive" and "informative" declarative pointing (Tomasello et al, 2007). In the expressive subtype, the child seeks to share his or her enthusiasm with an adult about a common referent, while in the informative subtype, the child points to an object in order to help the adult, providing him/her with the information he/she needs. Tomasello et al. (2007) regard these gestures as subtypes of declarative pointing because they both rely on psychological processes that go well beyond the conception of the adult as a causal agent, as opposed to imperative pointing.

The fact that imperative and declarative pointing gestures are used in different contexts and for different purposes raises the question of their origin. Some gestures are derived from practical actions and acquire a communicative function via a process called “ontogenetic ritualization” (Tomasello & Call, 1997). An action gradually becomes ritualized into a communicative signal through a partner’s reaction to it. Imperative pointing, which is regarded as being equivalent to a request gesture, may originate from simple reaching actions. This abstraction from object-directed actions may account for similar structural characteristics, namely for the use of the whole hand. By contrast, declarative pointing gesture, as a means of sharing an attitude about a common referent with other individuals, may develop through social interactions and imitation processes. Several differences that have been observed between imperative and declarative pointing support the hypothesis of different origins for these gestures. Camaioni et al. (2004) assessed the understanding of adults’ intentions by infants at the ages of 12 and 15 months through their ability to reproduce other people’s intended acts after observing them fail to perform these acts. They found that the ability to understand intentions was linked to the production of declarative, but not imperative pointing. Moreover, declarative pointing emerged later than imperative pointing (e.g, Camaioni et al., 2004). A study has also shown that comment gestures, including declarative pointing, predict later communicative competence on the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981), whereas reach-request gestures produced at the beginning of the first year are negatively correlated to language measures at 3 years (Blake, Vitale, Osborne, & Olshansky, 2005). Imperative function thus does not seem to be related to verbal communication. By contrast, declarative pointing in toddlers already reflects features of human language, namely social cognition and cooperation. As the main language functions are lateralized in the left cerebral hemisphere in the vast majority of people, investigating handedness for imperative and declarative pointing may shed light on the potentially different nature of these gestures. We may then observe different forms and degrees of right-handedness, depending on the function and origin of the pointing gestures. For instance, if imperative pointing is ritualized from a reaching action, we may observe more gestures produced with the whole hand, compared with declarative pointing. Gestures involving a request function may also be less right-handed than declarative ones.

The present study focused on several features of pointing gestures: handedness, form, function and the links between pointing and verbal behavior. Never before had all these aspects been studied together in humans, and we believed that recording observations was an efficient way of doing so. The aim of our investigation was thus to provide an overview of the entire range of forms and functions of pointing gestures produced by young children using naturalistic methods, that is through the observation of their spontaneous communicative gestures at daycare centers. Our first hypothesis was that we would find a right bias for communicative gestures, in line with several previous studies (e.g., Bates et al., 1986; Vauclair & Cochet, submitted; Young et al., 1985). Our second hypothesis concerned the difference between the right bias of gestures produced on their own and the bias of gestures produced with vocalizations, the assumption being that the latter would be stronger than the former. Finally, we hypothesized that the pattern of pointing gestures would vary according to their intended function. We expected to observe differences in both the handedness and the form of the gestures, depending on their imperative or declarative function.

Table 1. Mean number of sessions depending on the age of the participants.

Age range	Mean number of sessions ± S.D.	N
11.5 – 20 months	8.36 ± 2.3	11
20 – 29 months	7 ± 2.6	8
29 – 38 months	8 ± 2.5	7

Method

Participants

The participants were 26 children (15 girls and 11 boys), observed at a daycare center. These children were divided into four groups which attended the daycare center on different moments (four different half days), including two groups of 7 (4 girls and 3 boys) and two groups of 6 (2 girls and 4 boys for the first one; three girls and three boys for the other one). Six female nursery staff members were always present with the children, interacting with and looking after them. Children were observed between 5 and 10 separate sessions depending on the group, over a three-month period. The sessions were each separated by at least one week and at most three weeks. Children were observed during three-hour blocks of time, in the morning or in the afternoon, resulting in a total observation time of approximately 100 hours. The mean number of sessions per child was 7.85 (*S.D.* = 2.4), corresponding to a mean duration of 23.5 hours of recording (*S.D.* = 7.2).

Children were aged between 11 months and 16 days and 37 months and 24 days on the first day of observation (M = 23.6; *S.D.* = 6.9). There was no significant difference in the mean number of sessions as a function of age, $F(2;23) = 0.74$; *ns* (see Table 1).

Procedure

The observations were conducted during free play times and included a snack time. In order not to interfere with the different activities and interactions, the observer always remained on the periphery of the group. As this study focused on pointing gestures, data were collected using a behavior-dependent sampling method. The small size of the groups being observed allowed the experimenter to record all the communicative pointing gestures accurately and efficiently on a datasheet, as and when they occurred. The observer was highly trained to record infants' gestural behaviors and she had spent a few days in the day-care center before starting the data collection, in order to observe the interactions between children.

Pointing gestures were defined as the extension of the arm towards a referent (object or event) involving a clear communicative intention through gaze, vocalization or other clear evidence of an effort to direct someone's attention. Several features characterizing pointing gestures were then taken into account. The observer (HC) first noted whether the gesture was produced with the index finger extended and the other fingers curled or with a less conventional form and all fingers extended ("whole-hand" pointing, Leavens & Hopkins, 1999). For each gesture, the observer recorded which hand was used and whether or not the gesture was accompanied by a vocalization. Vocalizations consisted of either words or other vocal communicative productions (e.g., pseudowords or speech sounds). Whining and crying were not included. Vocalizations were considered to be produced co-temporally with a gesture when the two events occurred simultaneously or within a two-second interval. The observer also noted whether or not the pointing gesture was coordinated with gaze alternation, that is, whether children shifted their gaze between the target and the social partner while pointing or within a two-second interval after the production of the gesture.

Each pointing gesture was also classified according to its function. When the child pointed to an out-of-reach object so that the adult gave him/her or did something with it that the child could not do by him/herself, it was coded as an imperative pointing. When the child sought to direct a recipient's attention toward a referent in order to share interest in it or provide the recipient with helpful information, the gesture was coded as a declarative pointing. In some cases, when the child's intention was not obvious at first sight, the observer relied on the adult's behavioral reaction to the child's pointing and on the child's behavior following the adult's first reaction. For example, a gesture was classified as imperative if the child showed signs of satisfaction and ceased the gesture after the adult gave him/her the object pointed at, and as declarative if the gesture ceased after the adult commented on the referent (see Carpenter, Nagell, & Tomasello, 1998).

Within the more general category of declarative behaviors, we initially distinguished between the informative function (e.g., when the child helps the adult by pointing to an object he/she is looking for) and the expressive function (e.g., when the child wants the adult to see an event of interest and share enthusiasm about it) (Tomasello et al., 2007). However, as fewer than five informative pointing gestures were produced overall, we decided to group these two functions into a single category.

In order to avoid any effects of positional bias on hand use, gestures were only recorded when (1) the child was in a symmetrical posture (the body was in a straight position and both arms were at an equivalent distance from the body) with both hands initially free, and (2) the referent was positioned centrally in front of the gesturer. Even when several individuals meeting these two criteria were pointing at the same time (something which happened very rarely), the observer was still able to score the pointing behaviors of two individuals simultaneously. If more than two children were pointing simultaneously, instead of trying to record all the gestures, the experimenter chose two of them in order to maintain a comparable number of observations for each participant: if the number of data points previously recorded for one individual was already high, this individual child's pointing was not recorded. However, this only happened three times during the 100 hours of observation.

The sessions were videotaped for two groups in order to evaluate interobserver reliability (the camera was placed in a corner of the room). We were not allowed to film the two other groups because some parents did not give their agreements. Analyses of variance did not reveal any difference between groups for any variables.

Reliability

Reliability was assessed on a subset of the videotaped sessions (approximately 15h) by an independent coder who was blind to the hypotheses of the study. The data obtained by the first observer from sheet recording were compared to the data recorded by the second observer from videotapes. First, 63 gestures produced by 12 children (12.5% of the total number of gestures) were recognized as communicative by both coders (inter-observer agreement was 100%). Within these 63 gestures, the analyses revealed high to very high inter-observer reliability. Cohen's kappa statistics for coding decisions were 1 for the hand used, .85 for the function of the pointing gesture, .71 for handshapes, .82 for vocalizations and .65 for gaze alternation.

A few gestures could not be taken into account for the assessment of reliability when the video was not perfectly centered on the child's gesture (which could not be avoided as there was only one camera in the room), or for example, when an adult passed in front of the camera. Nevertheless, as the high agreement between coders highlighted the reliability of the data recorded by the observer, these gestures were included in the analyses.

Data analysis

The data were summed across the test sessions. An individual handedness index score (HI) was calculated for each child using the formula (R-L)/(R+L), where R and L stand for the total right- and left-hand responses. The HI values lay along a continuum from –1 to 1, with the +/- sign indicating hand-preference direction and the absolute value reflecting hand-preference strength. Handedness indices were calculated for pointing gestures and analyzed with respect to their form (index-finger versus whole-hand pointing), function (declarative versus imperative pointing) and vocalizations (gestures that were accompanied by vocalizations versus those that were not). All analyses were performed using parametric statistics with alpha set to $p < 0.05$.

Results

Hand preference for pointing

A total of 503 gestures were collected (93.4% of which were addressed to an adult) and the number of observations per participant varied from 5 to 63 (M = 19.3; S.D. = 15.1). As expected, we observed a significant right-hand bias for communicative gestures, as 428 gestures (85.1%) were right-handed and 75 (14.9%) were left-handed. The mean numbers of right-handed and left-handed gestures produced were 16.5 (*S.D.* = 13.8) and 2.9 (*S.D.* = 3.1), respectively ($t(26) = 4.91$; $p < .001$). Handedness scores varied between 0.11 and 1 and the mean handedness index was 0.68 (*S.D.* = 0.25).

Gaze alternation

Each of the 26 children exhibited gaze alternation between the object of the pointing gesture and the face of the recipient. Gaze alternation was observed in 56.5% of cases. There was no significant difference between the mean number of gestures accompanied by gaze alternation (*M* = 10.9; *S.D.* = 9.8) and the mean number of gestures produced without gaze alternation (*M* = 8.4; *S.D.* = 7.2, $t(26) = 1.05$; *ns*).

Accompanying vocalizations

A total of 435 pointing gestures were accompanied by a vocalization (86.5%) and 68 (13.5%) were not. Children's gestures were significantly more frequently accompanied by vocalizations (*M* = 16.7; *S.D.* = 13.7) than produced on their own (*M* = 2.6; *S.D.* = 2.9; $t(18) = 5.16$; $p < .001$). To test our second prediction, we assessed whether the right-hand bias for pointing gestures was stronger when these gestures were accompanied by vocalizations. Eight of the 26 children only produced gestures accompanied by vocalizations, so they were excluded from the analysis. No significant difference was observed between HI for pointing accompanied by vocalizations (vocal HI) and HI for unaccompanied pointing (non-vocal HI) ($t(18) = 0.067$; *ns*). Our results therefore did not confirm our initial hypothesis. It should, however, be noted that because of the small number of pointing gestures produced without any vocalization ($M = 2.6$, $S.D. = 2.9$), the handedness scores associated with these gestures may not have been entirely representative of the children's degree of handedness. The comparison between vocal HI and non-vocal HI should thus be interpreted with some caution.

Form and function of pointing gestures

Every child produced pointing gestures with the index finger extended and 20 of the 26 participants also produced whole-hand pointings. Four hundreds and fourteen pointing gestures (82.3%) were characterized by the conventional extension of the index finger, whereas 89 gestures (17.7%) were produced with the whole hand. Children's gestures were significantly more frequently produced with the index extended ($M = 15.9$; $S.D. = 14.2$) than with the whole hand ($M = 3.4$; $S.D. = 4.0$; $t(20) = 4.33$; $p < .001$).

Regarding the communicative intent of the pointing gestures, 160 gestures (31.8%) had an imperative function and 343 gestures (68.2%) a declarative one, be it sharing an interest in an object or event or providing helpful information to the recipient. Four children used pointing gestures only in the declarative context. The mean number of declarative gestures ($M = 13.2$; $S.D. = 12.2$) was significantly greater than the mean number of imperative gestures ($M = 6.2$; $S.D. = 6.4$; $t(22) = 2.60$; $p < .05$).

On average, 94.1% of declarative pointing gestures were produced with the extended index finger versus 53.9% of imperative pointing gestures. This difference was significant ($t(22) = 5.61$; $p < .001$).

We first investigated which handshape more frequently characterized imperative and declarative functions, and then, reciprocally, we examined which function index-finger and whole-hand pointing were more frequently used for. As far as declarative pointing is concerned, the mean number of gestures produced with the index finger was higher than the mean number of whole-hand gestures ($t(26) = 5.02$; $p < .001$). This difference was observed for both right-handed ($t(26) = 4.70$; $p < .001$) and left-handed pointing ($t(26) = 3.66$; $p < .001$). As far as imperative pointing is concerned, there were no significant differences in the mean number of gestures produced as a function of handshapes ($t(26) = 0.37$; *ns*), either for right-handed gestures ($t(26) = 0.44$; *ns*) or for left-handed ones ($t(26) = -0.47$; *ns*). The mean proportions of declarative and imperative pointing gestures produced according to gesture form are shown in Figure 1.

Index-finger pointings were more frequently used with a declarative function than with an imperative one ($t(26) = 4.14$; $p < .001$). Whole-hand gestures, on the contrary, were more frequently produced with an imperative function ($t(26) = 3.86$; $p < .001$). This was true for both right-handed ($t(26) = -3.40$; $p < .01$ for index-finger gestures and $t(26) = 3.35$; $p < .01$ for whole-hand gestures) and left-handed gestures ($t(26) = -2.88$; $p < .01$ for index-finger gestures and $t(26) = 2.43$; $p < .05$ for whole-hand gestures).

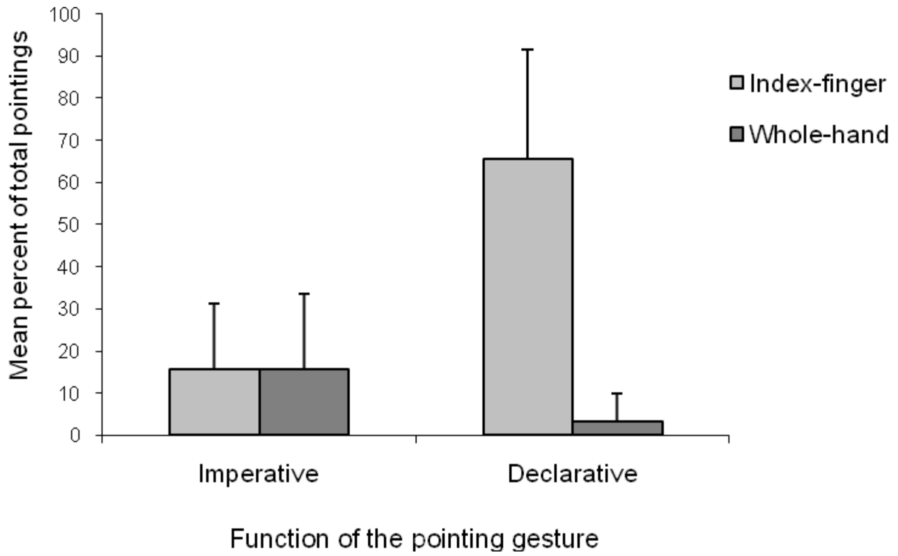

Figure 1. Mean proportions of declarative and imperative pointing gestures according to gesture form.

The HIs for declarative and imperative pointing were compared using Student's t-test. Mean HIs (0.74 ± 0.24 and 0.75 ± 0.32, respectively) did not differ (t(22) = -0.11; *ns*). We also compared the HIs for index-finger pointing and whole-hand pointing, but there was no difference either in the degree of the right-hand bias (t(20) = -0.81; *ns*).

Our third hypothesis was thus partially confirmed, insofar as the form of the pointing gestures, though not their handedness pattern, varied according to the function of the gesture. Moreover, another feature appeared to differ between imperative and declarative pointing: the proportions of imperative and declarative gestures produced simultaneously with vocalizations were respectively 58.8% (*S.D.* = 35.6) and 91.7% (*S.D.* = 14.7). Declarative gestures were thus more frequently accompanied by vocalizations than imperative gestures (t(22) = -4.00; $p < .001$).

Regarding visual behavior, there was no difference between the two types of pointing in the mean proportions of gestures accompanied by gaze alternation (t(22) = 0.08; *ns*).

Gender

There was no significant difference in pointing behavior according to gender, either in the total number of gestures produced (t(26) = -0.95; *ns*), the handedness index associated with pointing (t(26) = -1.72; *ns*) or the function of the gestures (t(26) = 0.38; *ns*).

Age

There was no significant relationship neither between the age of the participants and the total number of gestures they produced (r = -0.24; *ns*), nor between age and the degree of right-handedness associated with pointing (r = 0.24; *ns*). The right-hand bias did not become stronger with age. Moreover, the proportion of gestures produced with accompanying vocalizations did not increase as a function of age (r = 0.31; *ns*). But we observed significant relationships between age and function of pointing gesture (r = 0.55; $p < .01$) and between age and form of gesture (r = 0.53; $p < .01$). As illustrated in Figure 2, when children grew older, they produced an increasing number of pointing gestures with a declarative function and with the index finger extended.

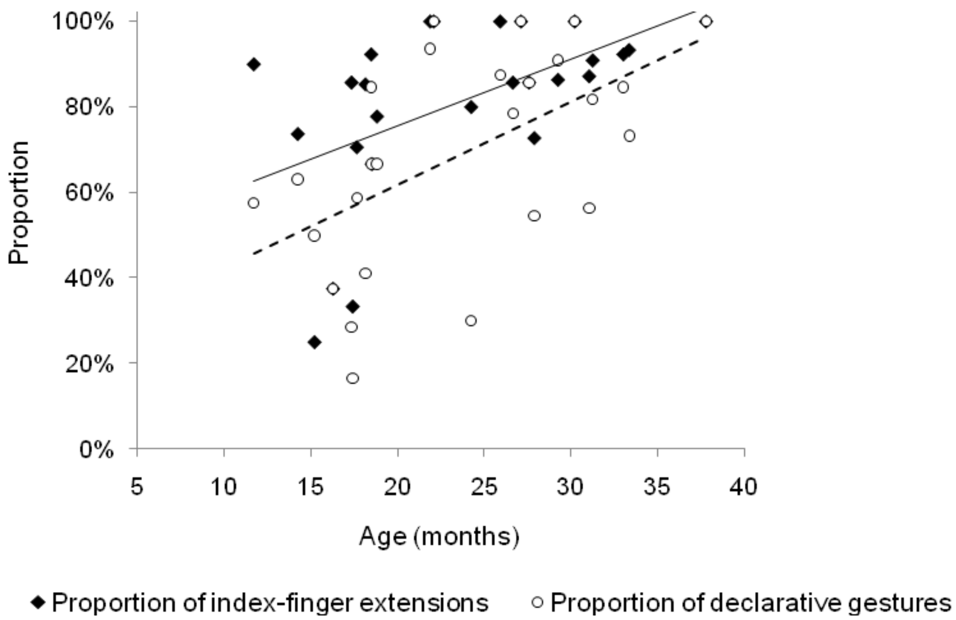

Figure 2. Relationship between age, proportion of index-finger extensions (solid line) and proportion of declarative gestures (dashed line).

Discussion

This research was designed to probe the features of spontaneous pointing gestures in young children. To our knowledge, it was the first study to investigate the characteristics of pointing gestures under naturalistic conditions in a day care centre. The observation of these spontaneous gestures may shed new light on the development of communicative behavior in toddlers. The results showed a strong and significant right-hand preference for pointing gestures, in line with previously reported findings (Bates et al., 1986; Blake et al., 1994; Young et al., 1985). The mean Handedness Index (HI) observed in the present study (0.68) was stronger than the mean HI for pointing reported by Vauclair and Imbault (2009) in experimental conditions (0.52). This difference may simply be due to the absence of left-handed participants in the present study (all the HI were positive), which was not the case in the study by Vauclair and Imbault (2009), as they recruited a larger sample of participants.

The right-handed bias did not increase as children grew older, that is, between approximately 1 and 3 years of age (the youngest participant was aged 11 months and 16 days at the beginning of the observations and the oldest one was 37 months and 24 days). A study of toddlers aged 13-28 months (Bates et al.., 1986) also failed to reveal any strengthening of the right-sided asymmetry over this period. An increase in the right-sided bias for pointing gestures had previously been reported, but it concerned lower age ranges than those selected for the present study (Blake et al., 1994; Young et al., 1985), indicating that the increasing involvement of the left cerebral hemisphere in the production of communicative gestures may take place even before children reached one year of age.

Communicative signals were expressed simultaneously in the gestural and vocal modalities in 86.5% of cases. This widespread use of vocalizations contrasts with results obtained with nonhuman primates, showing that the majority of gestures are not accompanied by vocalizations (Hopkins & Cantero, 2003). The specificity of human communicative behavior, which lies in the vocal modality, therefore appears at a very early stage in development. Furthermore, it is interesting to note that the recipients of referential gestures produced by children were adults in the majority of cases. This result suggests that communicative skills may develop through interactions with adult caregivers and not with other children, in line with previous studies emphasizing the influence of adults' inputs (e.g., Kishimoto, Shizawa, Yasuda, Hinobayashi, & Minami, 2007).

We did not observe any difference in the degree of right bias between gestures produced alone and gestures produced simultaneously with vocalizations, apparently disproving our hypothesis that a greater demand is placed on left hemisphere resources when both modalities are involved simultaneously. However, this finding may be explained by the relatively low number of gestures produced without vocalizations (the mean number of pointings produced on their own was 2.6 and eight children did not produce any at all). Consequently, the comparison of handedness scores for gestures produced with and without vocalizations was not based on an equivalent number of gestures. Moreover, no attempt was made in the present study to characterize the vocalizations and words produced by the children. It would be useful to study in a future research the different features of these communicative signals in greater depth, possibly using spectrographic analysis. A sound spectrograph would provide measures of the tone, rhythm, amplitude and frequency of vocal sounds, which could help to distinguish between different vocalizations.

A significant relationship was observed between the form and function of pointing gestures. Index extensions were more frequently used with a declarative function, whereas whole-hand gestures were more frequently produced with an imperative function. Moreover, in the vast majority of cases, declarative pointing was produced with the index finger, whereas imperative pointing was characterized equally by index-finger and whole-hand extensions.

These different structural characteristics, as well as the different motivational backgrounds of imperative and declarative pointing gestures, may be related to their different origins. Imperative gestures were more frequently associated with whole-hand extensions, which superficially resemble acts of prehension, than declarative gestures were. It may thus be hypothesized that imperative pointing substitutes for reaching actions by a process of ontogenetic ritualization (Tomasello & Call, 1997). A behavior that is not initially a communicative signal becomes one through reciprocal social interactions: the child learns over repeated instances that his/her gesture elicits a particular action from the adult (in this case, the action of giving the child the desired object). Vygotsky (1988) had previously argued that pointing develops out of reaching, but this hypothesis only seems consistent with the imperative function of pointing.

Declarative pointing, by contrast, would not appear to emerge from a ritualization process, as almost all declarative pointing gestures were produced with the extended index. It has been suggested that index-finger pointing emerges not from a less differentiated form, but from the non-communicative finger extensions observed in infants from three months onwards (Butterworth, 2003; Masataka, 2003). One argument advanced to support this assumption concerns the changes that take place in the gestural repertoire in the course of early development: the frequency of index-finger extensions increases between 3 and 11/12 months, then decreases, whereas the frequency of index-finger pointing gestures starts to increase (Masataka, 2003). For this reason, among others, index-finger pointing is sometimes viewed as the basic and natural form of reference, which develops spontaneously (Butterworth, 2003). However, investigations of deictic behaviors in different cultures have revealed variations in the form of pointing gestures, indicating that index-finger pointing is not the universally preferred referential strategy. In some cultures, for example, lip-pointing is dominant and forms of manual pointing that are never or rarely encountered in some cultures are frequently observed in others, such as when the middle finger, not the index finger, is pointed toward a target (Kendon & Versante 2003; Wilkins, 2003).

These observations suggest that the use of the index finger for pointing is not universal and is, at least to some degree, socially transmitted to the infant. The development of index-finger extensions in the present study may indeed have involved an imitation process. When adults used pointing gestures to communicate with children, they did so with a declarative motive rather than an imperative one, and with the extended index. They sought to direct the child’s attention toward a referent in order to share interest in it, for example when looking at pictures in a book. Fewer, if any, examples come to mind of a parent pointing with the whole hand toward an object so that the child will bring it to him/her. Studies should be conducted to investigate the function of pointing gestures produced by caregivers when interacting with children in order to help determine whether imitation is the major learning process at work in the development of declarative pointing.

We can thus raise the hypothesis that imperative and declarative pointing gestures develop in parallel and independently. Different developmental sequences in the emergence of imperative and declarative pointing have previously been reported: declarative pointing develops later than imperative pointing (e.g., Camaioni et al., 2004). Moreover, authors have shown that children with autism fail to understand and produce declarative pointing, but not imperative pointing (Camaioni, 1997). This hypothesis is also reinforced by the relationship reported in the present study between age and the function of the gesture. As children grow older, they use more and more pointing gestures in declarative contexts and with the index finger extended.

This increasing use of index-finger pointing may reflect a developmental tendency toward more symbolic forms of communication (e.g., Franco and Butterworth, 1996). This hypothesis is supported by studies of nonhuman primates, as language-trained chimpanzees point more frequently with their index fingers than chimpanzees which have not experienced close relationships with humans (Leavens &

Hopkins, 1999). The extension of the index is then particularly likely to be observed in the context of close relationships with humans. Note that this is a favorable context for imitation to occur, but so far, this assumption has not been confirmed by empirical evidence, as some studies have reported that chimpanzees do not imitate (see Tomasello, 2006).

Even if the majority of whole-hand pointings were used in imperative contexts, imperative pointing gestures were produced both with the whole hand and with the index finger. Therefore, our initial proposal that imperative pointing and "request gestures" (e.g., Capirci et al., 2005) are identical communicative signals proved not to be entirely satisfactory. These gestures may share the same function, but their respective forms are somewhat different. As a few studies have observed a decrease in the production of reaching gestures (described as communicative and imperative gestures with all fingers extended) as children grow older (e.g., Blake, McConnell, Horton, & Benson, 1992), we can assume that early imperative pointings are produced with the whole hand and later on with the extended index. This progressive shift in handshapes might be related to a progressive shift in the cognitive processes associated with imperative gestures. Tomasello and colleagues (2007) suggested that imperative motives form a continuum from ordering to suggesting. It could then be hypothesized that at an early stage, children understand the adult as a causal agent from whom they can get what they want, and later on, while imperative pointing becomes more frequently produced with the index-finger, the adult is regarded as an intentional agent who can decide to help the children. This perspective entails the possibility that the production of imperative pointing is different between non human primates and human children, that is, is related to different cognitive and social skills. In line with this hypothesis, it has been shown that human infants were able to request absent objects, whereas chimpanzees did not possess this ability (Liszkowski, Schäfer, Carpenter, & Tomasello, 2009).

Moreover, as the declarative gestures were almost exclusively characterized by index finger extension in the present study, we can also hypothesize that declarative pointing influences the structural characteristic of all deictic behaviors. Once index-finger pointing appears in the child's gestural communication system, imperative pointing behavior may gradually be modified to feature the index extension. Note that this does not exclude the possibility that imperative pointing may originate from non-communicative actions, or the idea that imperative and declarative pointing are functionally distinct.

More globally, the relationship between handshapes, functions and origins of pointing gestures is a complex issue, and as suggested by Tomasello (2006), some infants may learn to use pointing in one way and some in the other way. Even if the results of the present study showed some predominant developmental patterns in the production of pointing, there might be different developmental trajectories. For example, approximately 6% of declarative pointing gestures were produced with the whole-hand, by children who also produced declarative index-finger points. Given the purpose of declarative pointing, it is unlikely that these whole-hand gestures emerge from prehension, but it remains very difficult to find out, empirically, whether pointing gestures are ritualized from reaching actions or learned though imitative process.

The distinction between imperative and declarative pointing was expected to encompass different patterns of handedness, reflecting different degrees of involvement of the left cerebral hemisphere. Imperative pointing, at least in the early stages, relies solely on the representation of people as causal agents, whereas declarative pointing implies the ability to represent and influence another person's attentional state, which is a crucial step in communication (Camaioni et al., 2004). Declarative pointing was thus expected to be more right-handed than imperative pointing, but in the event we failed to observe any handedness differences between the two types of gestures. Unless the difference in activation levels is too subtle to be reflected in manual preferences, imperative and declarative points may involve the left cerebral hemisphere to an equal extent, insofar as they are both communicative gestures. Moreover, some researchers do not support a cognitive distinction between imperative and declarative gestures. On the one hand, both types of gestures are regarded as instrumental acts that do not involve the understanding of others' attention (e.g., Moore & Corkum, 1994), and, on the other hand, both imperative and declarative gestures would reveal an early form of psychological understanding (e.g., Liszkowski, 2005). This latter perspective has recently been supported by empirical findings (e.g., Liszkowski et al., 2009).

However, even if imperative gestures may not be related to simpler cognitive processes than declarative gestures, a clear distinction between both types of gestures in the present study relied on the incidence of accompanying vocalizations. Declarative gestures were more likely to be produced with vocalizations compared to imperative gestures, which emphasizes the close relation between declarative gestures and the vocal system. This result is important insofar as it may reflect different roles played by imperative and declarative pointing in language development. It would then be useful for future studies to measure children's language levels, in order to investigate whether language abilities are more strongly correlated with declarative than with imperative gestures.

Within declarative pointing, some authors have distinguished between the expressive and the informative function (e.g., Liszkowski, Carpenter, Striano, & Tomasello, 2006; Pika, 2008). The expressive function, the one examined in our study, refers to the intention of sharing an interest with a communicative partner about a referent, whereas the purpose of informative pointing is to provide the other person with information he/she needs. For example, if we see that another person has mislaid an object, and we know where it is, we will point in its direction to help that person. This gesture, which is within the capability of 12-month-olds, involves an understanding of others as people with intentional and informational states. Informative pointing has been studied within experimental contexts, where artificial situations have been set up to elicit this gesture (Liszkowski et al., 2006). For instance, the experimenter, without apparently noticing, accidentally drops an object on the floor and then starts looking for it. The child is then likely to point toward the object. In the present study, very few instances of informative pointing were observed. Opportunities for a child to provide an adult with useful information were probably few and far between, but we can also assume that this gesture is not willingly produced outside a standardized context. Even if experimental studies of informative pointing are interesting from both a cognitive and a motivational point of view, it is noteworthy that this gesture is not really part of toddlers' spontaneous gestures.

All 26 children exhibited gaze alternation between the object of the pointing and the face of the recipient, but pointing gestures were not always associated with this behavior. Gaze alternation is usually regarded as a hallmark of intentional communication (e.g., Bates et al., 1975). The fact that gaze alternation did not consistently accompany pointing gestures in our study could therefore call into question the nature of the pointing gestures we recorded. Nevertheless, several factors need to be taken into account when deciding whether a communicative gesture is intentional and infants' gaze alternation may be influenced by many factors (Liszkowski, Albrecht, Carpenter, & Tomasello, 2008). In the present study, the respective positions of the gesturer, recipient and referent of the pointing did not necessarily allow the child to alternate his/her gaze between the object and the adult. For example, if the child was seated on the adult's lap when pointing to a referent in front of him/her, gaze alternation was probably not observed because the child would have had to have turned round to see the adult's face. More generally, gaze alternation was less likely to occur when the adult and child were looking in the same direction. It was then easier for the child to direct the adult's attention to a referent and he/she probably felt less inclined to check the efficiency of his/her gesture via gaze alternation. Thus, pointing cannot be classified as communicative or non-communicative simply on the basis of visual orienting behavior (e.g., Liszkowski et al., 2008; Murphy, 1978). Future studies therefore need to focus more carefully on the situations in which the pointing gesture is produced. In a study comparing the declarative and requestive functions of communicative gestures, visual checking was found to be more closely associated with the declarative function of pointing (Franco & Butterworth, 1996). This result was not observed in the present study, but Franco and Butterworth (1996) investigated visual behavior in experimental conditions that allowed the children to adopt standardized postures. As a consequence, they were not concerned with the different positions of the communicative partners and the extent to which they would favor gaze alternation.

Taken together, our results emphasize the relevance of distinguishing between imperative and declarative functions of pointing when investigating the development of communicative gestures in a natural setting. The results of the present observational study need to be investigated in experimental studies, where specific situations would elicit imperative and declarative pointing gestures. Standardized contexts would provide a fruitful comparison with our study regarding handedness, form and function of pointing gestures.

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4.3. Aims of article III

One of the purposes of this study was to replicate findings of the observational study (article II) using experimental tasks to elicit pointing gestures in different communicative contexts. In order to explore further the different functions of pointing gestures, an additional distinction was made within declarative gestures between expressive and informative pointing (Tomasello et al., 2007), the latter being scarcely produced by children in natural conditions. As in the previous study, we focused on several features associated with pointing gestures, including hand preferences, hand shapes, gaze direction and accompanying vocalizations.

4.4. Article III: Cochet, H., & Vauclair, J. (2010). Pointing gestures produced by toddlers from 15 to 30 months: Different functions, hand shapes and laterality patterns. *Infant Behavior and Development, 33*, 432-442.

Pointing gestures produced by toddlers from 15 to 30 months: Different functions, hand shapes and laterality patterns

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Abstract

Three experimental designs were implemented in day nurseries in order to elicit imperative, declarative expressive, and declarative informative pointing gestures (Tomasello, Carpenter, & Liszkowski, 2007) among a population of 48 toddlers aged 15-30 months. Several features were recorded for each situation, including gesture form, gaze direction, and vocalizations. A unimanual reaching task was also administered, in order to compare laterality patterns for each type of gesture. Main results revealed that imperative gestures were associated with whole-hand pointing, whereas declarative gestures were more frequently characterized by an extended index finger. Moreover, declarative gestures were more frequently accompanied by vocalizations than imperative gestures were. Finally, different degrees of manual preference were observed, especially for informative pointing gestures, which tended to be more right-handed than reaching actions. Results of the study are discussed in relation to the nature and development of each kind of pointing gesture.

Keywords: toddlers, pointing gestures, imperative - declarative expressive - declarative informative functions, hand shapes, handedness.

Introduction

Infants start to communicate intentionally through gestures toward the end of their first year (e.g., Butterworth & Morissette, 1996; Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004). In addition to their pragmatic impact (gestures vastly increase communicative resources), communicative gestures also play a key role in the early development of social-cognitive abilities (e.g., Carpenter, Nagell, & Tomasello, 1998) and serve as a foundation for the development of language (e.g., Iverson & Goldin-Meadow, 2005; Rowe & Goldin-Meadow, 2009). The predictive and facilitative relationship between gesture and speech has mainly been highlighted in the context of the pointing gesture (e.g., Pizzuto & Capobianco, 2005). The latter shares common mechanisms with speech, as it enables children to interact with adults and to communicate their intentions, requests and feelings about a specific referent. It is a complex gesture, whose meaning depends on the nature of the concrete object or situation that is being referred to, as well as on the circumstances in which the gesture is used (e.g., Tomasello et al., 2007).

Moreover, there is considerable variability in the expression of pointing gestures, especially when we focus on their function. In an early study, Bates, Camaioni, and Volterra (1975) made a distinction between protoimperative and protodeclarative gestures, the former being defined as the “use of the adult as a means to a desired object” and the latter as the “use of an object as the means to obtaining adult attention” (p. 209). Both protoimperative and protodeclarative gestures were thus initially described as instrumental acts towards some physical or social goal. Several authors later defended the idea that infants’ early pointing aimed at gaining positive emotional reactions to the self rather than directing the attention of others to external entities and that neither imperative nor declarative pointing involved the understanding of others’ attention (e.g., Moore & Corkum, 1994; Moore & D’Entremont, 2001; Racine & Carpendale, 2007).

By contrast, others researchers opposed imperative and declarative gestures, arguing that declarative pointing reveals an early form of psychological understanding (e.g., Pika, 2008; Tomasello, 1995). Children would use imperative pointing to ask someone to do something for them (e.g., the child points to an unreachable object as a request to be given it), whereas declarative gestures would be used to direct the addressee’s attention to a referent for reasons other than achieving egocentric goals (e.g., children point to the plane they have just seen in the sky so that their parents can see it, too, and share in their enthusiasm). Declarative pointing would thus demonstrate that infants understand others as attentional and intentional agents (e.g.,Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). More recently, Tomasello and colleagues (2007) distinguished between expressive declarative gestures, when the child seeks to share interest in an object, event or location, and informative declarative gestures, when the child cooperates with adults and gives them some information they need (see also Liszkowski, Carpenter, Striano, & Tomasello, 2006).

Evidence from autistic children, who have problems with declarative communication, but are able to produce and understand imperative gestures (e.g., Camaioni, 1997; Camaioni, Perucchini, Muratori, & Milone, 1997), suggests that imperative and declarative pointing gestures are associated with different underlying social and cognitive mechanisms. Studies of nonhuman primates support the notion of a split between imperative and declarative communication, as the gestures produced by these species also seem to lack the declarative function (e.g., Leavens, Hopkins, & Bard, 1996), although there have been a few reports of apparently declarative gestures in language-trained apes (see Leavens, 2009). It has been argued that early emotional bonding with caregivers plays a role in the ability to develop declarative communication (Leavens, 2009), given that the few declarative gestures recorded in nonhuman primates were produced by apes that had experienced close emotional ties with humans. However, declarative gestures may also involve more complex social and cognitive skills, which are necessary for the development of speech, such as theory of mind and cooperation abilities (e.g., Liszkowski, 2005). A study of 12-15-month-old toddlers revealed that the production of declarative pointing gestures, but not imperative gestures, was linked to the understanding of adults' intentions (Camaioni et al., 2004). Imperative pointing gestures, even though they are intentional and referential, may be less cognitively demanding. The process involved in controlling these gestures, at least at a very early stage, may be similar to operant conditioning: children's pointing gestures are followed by adults' giving them the desired object (positive reinforcement). This would lend meaning to the gestures and enable young children to "operate" on the environment.

The question then arises as to whether imperative and declarative pointing gestures have different origins. Vygotsky (1988) argued that pointing gestures develop out of failed reaching. However, although this idea is consistent with the request function of pointing gestures (reaching actions and imperative pointing gestures share the same ultimate goal, i.e., obtaining a desired object), it seems unlikely that declarative pointing emerges from reaching actions, as illustrated by the following examples. Try to imagine what infants do when they want their mother (or father) to give them the biscuits that are out of reach on the table. They begin by initiating the action of reaching for and taking the biscuits. The mother then understands that they want some biscuits and may decide to give them some. By this means, children learn about the relationship between their own actions and the effects of these actions on adults. Tomasello and Call (1997) refer to this process, by which an action becomes a communicative signal thanks to the partner's reaction, as *ontogenetic ritualization*. But what happens when children are surprised by a particular event, such as a cat walking through the garden, which their mother has not seen? Rather than trying to reach out and take hold of the cat, the children may instead want to direct the adult's attention to it and provoke some enthusiasm. To find a way of communicating in this specific context, children have no choice but to dip into the gestural repertoire that is already stored in their memory. And what children are most likely to have seen in previous declarative situations is adults producing indexical pointing gestures, in order to direct their attention to some external referent. Imitation, and even deferred imitation, might thus play a key role in the development of declarative pointing. A longitudinal study has shown that deferred imitation in 9-month-old infants was the strongest predictor of communicative gesture production measured 5 months later (Heimann, Strid, Smith, Tjus, Ulvund, & Meltzoff, 2006). However, the authors unfortunately did not mention whether they distinguished between imperative and declarative gestures. And more globally, the idea of distinct origins for imperative and declarative remains hypothetical, as there is no direct evidence of the learning processes through which the different kinds of pointing are acquired.

A more empirically testable distinction between imperative and declarative pointing may concern hand shape variability. Not only do pointing gestures serve different functions, but they also take different forms, and this has been a source of disagreement between researchers regarding the definition of pointing itself. While all researchers agree that pointing is a communicative gesture through which a gesturer directs the addressee's attention to a specific referent, some of them consider that it can be produced either with the extended index finger or with the whole hand (e.g., Brooks & Meltzoff, 2008; Gullberg, de Bot, & Volterra, 2008; Krause & Fouts, 1997; Liszkowski, Carpenter, & Tomasello, 2008), whereas for others, pointing is restricted to index extension (e.g., Blake, O'Rourke, & Borzellino, 1994; Butterworth, Franco, McKenzie, Graupner, & Todd, 2002; O'Neill, Bard, Linnell, & Fluck, 2005).

In the present study, the broader of the two definitions was adopted and we investigated whether toddlers use different hand shapes for different functions. We implemented three experimental designs at day nurseries to elicit imperative, declarative expressive and declarative informative pointing gestures (Tomasello et al., 2007). If imperative gestures do indeed evolve from reaching actions, we would expect them to be characterized by a similar form, that is, whole-hand pointing. By contrast, declarative gestures, which might develop through imitation, should be more closely associated with index-finger pointing.

In addition, as communication involves a wide range of behaviors, both vocal and nonvocal, we described several other features of gestures in the three different experimental situations. Firstly, in order to compare interactions between gestural and vocal systems in each situation, we distinguished between gestures accompanied by vocalizations and gestures produced in isolation. Moreover, language level was assessed in order to examine whether declarative gestures have a closer relationship with language development than imperative gestures do. Gaze direction patterns were also studied, as gaze alternation between addressee and referent is usually regarded as one of the markers of intentional communication (e.g., Leavens, 2009). Pointing duration was measured, too. We hoped that all these variables would help us to identify the nature of children's intentions when producing imperative, declarative expressive, and declarative informative pointing gestures.

We also focused on manual preferences, as an indicator, albeit indirect, of cerebral asymmetries for gestural communication. While there is no longer any doubt as to the right-hand bias for pointing gestures (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Blake et al., 1994; Young, Lock, & Service, 1985), the question of whether imperative, declarative expressive, and declarative informative pointing gestures present different laterality patterns has yet to be answered. Our goal was therefore to compare the involvement of the left cerebral hemisphere between these three situations. Moreover, in order to investigate the contrast with handedness for manipulative actions, a simple unimanual task was included in the present study, in which children had to reach for and grasp objects. The comparison of hand preferences for reaching actions and for the different pointing gestures might help to shed light on the hypothesis of distinct origins for imperative and declarative pointing. Non-communicative manual actions have previously been reported as being less right-handed than pointing gestures in toddlers (Bates et al., 1986; Vauclair & Imbault, 2009). If imperative pointing gestures originate from reaching actions, we would expect to observe differences in the degree of hand preference between imperative and declarative gestures: imperative pointing would be less right-handed than declarative pointing.

Our hypotheses mainly concerned differences between imperative and declarative gestures, as it is more difficult to infer potential differences between declarative expressive and declarative informative pointing gestures. With declarative expressive pointing, children seek to share their interest in a specific referent, expecting the addressee to attend to this referent and show some enthusiasm (Liszkowski, 2005). Expressive pointing does not seem to require the same cooperative abilities as informative pointing. Little, however, is currently known about the specific characteristics of declarative informative pointing, other than that it involves the understanding of others as agents with informational states, and the motivation to cooperate with and help a communication partner, without any immediate benefit to oneself (Liszkowski et al., 2006). Our study might therefore yield some interesting information about the distinguishing features of these two kinds of declarative pointing.

Method

Participants

Forty-eight children (23 girls and 25 boys) attending four different daycare centers took part in the study. They were aged between 14.6 months and 31 months (M = 23.9; SD = 3.7).

Procedure

Depending on the daycare center, children were seen either in isolation in a separate room or in the main room but apart from the other children. All sessions were videotaped. Three experimenters were present in the room, including one standing behind the camera who noted down the behaviors as they were recorded. The two others interacted with the children and participated in the different situations described hereafter. Each participant in turn was seated at a rectangular table, with one of the experimenters sitting opposite him/her. Children had met the experimenters at least once before the day of the experiment and every session began with a short warming-up period so that the children did not feel insecure. Three pointing tasks and one unimanual grasping task were administered. Children undertook five trials for each task and the order of task presentation (unimanual grasping and pointing) was alternated across participants. Between the different tasks, the experimenter interacted with the children in order to maintain their attention.

For the *unimanual grasping task*, participants had to grasp small, different-colored balls that the experimenter put down on the table in front of them. All the children successfully performed the five trials of the grasping task.

The pointing tasks, presented in random order, were designed to elicit imperative, declarative expressive, and declarative informative pointing gestures (Tomasello et al., 2007). In each of the following situations, the experimenter reacted immediately and continuously for 5 seconds once the child pointed toward the specific referent, then the trial was over.

For the *imperative pointing task* (I), we used five attractive toys. The experimenter sitting opposite the child, between 1 and 1. 5m away from him/her, handled the object first. She showed interest in the toy, then gave it to the child for a few seconds before taking it back. The experimenter then put the object on the table, beyond the child's reach. The experimenter looked silently at the child for 15 seconds and gave the toy to the child if the latter produced a pointing gesture. If the child did not react, the experimenter said "Look at this! Isn't it pretty?" or something similar, and waited again for a further 15 seconds. The experimenter then gave the toy to the child.

For the *declarative expressive task* (DE), we used different-colored drawings of faces on 30 x 30 cm boards, between 1 and 1.5 m away from the child. The first experimenter (E1) sat opposite the child and interacted and played with him/her. The other experimenter (E2), hiding behind E1, suddenly held up one of the drawings twice, so that the child could see it but not E1. If the child pointed toward the drawing, the experimenter emoted positively about it for a few seconds. If the child did not react within 15 seconds once the board had disappeared, E2 held up the picture again in order to trigger a pointing gesture. The aim of the task was to create a sudden and unexpected event that the child would want to share with E1.

For the *declarative informative task* (DI), we used everyday objects that we thought would not be particularly attractive to the children, or at least, not as interesting as the toys used for the imperative task (e.g., a pen, a packet of lozenges, keys). E1 put the object down on the table (in front of the children, but out of reach (approximately 0.5 m away from them) and left the room. E2 came in, covered the object with a magazine so that the child could still see the object protruding from under it, and left. E1 came back and started searching for the object silently. If the child pointed, the experimenter retrieved the object and thanked the child for his/her help. If no pointing gestures were produced within 15 seconds, E1 asked "Where are my keys?", or an equivalent question, and waited for the child's reaction for a further 15 seconds.

Measures

In order to assess the children's language level, parents were asked to fill in the French adaptation (Kern, 2003) of the MacArthur Communicative Development Inventories (MCDI; Fenson et al., 1993). For the sake of comparison, we used the "Words and Sentences" questionnaire, designed for children aged between 16 and 30 months, to assess all the participants, instead of combining it with the one aimed at children between 8 and 16 months. The language score corresponded to the total number of words the children had in their vocabulary, according to their parents. Scores varied between 2 and 581 (M = 201; SD = 162) and significantly correlated with age ($r(42) = .63$; $p < .001$).

Regarding the children's visual behavior, we distinguished between gaze directed toward the referent (the object or event being pointed at), gaze directed toward the experimenter, and gaze alternating between experimenter and referent. The duration of the pointing gesture was also recorded. Moreover, we noted whether or not the gesture was accompanied by vocalizations. The latter, which could consist of any kind of vocal sound, had to be produced at the precise moment of the pointing gesture. Finally, the gesture was deemed to be a whole-hand point if all the fingers were extended, without any finger clearly distinct from the others, and an index-finger point when the index finger was extended and the other fingers were tightly or more lightly curled.

To measure handedness, we calculated individual handedness index scores (HI) with the formula (R-L)/(R+L), where R and L stand for the total number of right- and left-hand responses. The HI values lay along a continuum from –1 to 1, with the +/- sign indicating hand-preference direction and the absolute value reflecting hand-preference strength.

Reliability

All the behaviors we studied were first coded in real time by one of the experimenters. Two other experimenters then separately coded all the video recordings at the end of all the experiments in order to check the initial coding. There was 100% agreement between coders on hand preference, 100% on vocalizations, 98% on point duration, 86% on visual behaviour and 92% on hand shapes. When they disagreed over the interpretation of a behavior, the video was shown to a research assistant who settled the question.

Results

To present our results as clearly as possible, we focus, in turn, on the number of pointing gestures the infants produced, the form of these gestures, manual preference, vocal and visual behaviors, and finally, the duration of the pointing gestures. We also report how these different variables were related to age and language level.

Number of pointing gestures

Forty-seven of the 48 children produced pointing gestures. There were five trials for each of the three pointing situations, but children only produced a pointing gesture in 52% (*SD* = 24.5%) of them, that is, an average of 7.8 gestures across the 15 trials. Whereas age did not correlate with the overall number of pointing gestures produced, it did correlate with the proportion of declarative informative gestures ($r = .47$; $p < .001$), indicating that as children grew older, they produced more informative pointing gestures.

Hand shape

On average, 36.9% of the gestures produced by children took the form of whole-hand pointing (*SD* = 31.5) and 61.6% the form of index-finger pointing (*SD* = 32.1). The remaining 1.5% (*SD* = 5.8) were made up of other forms.[1] Figure 1 shows the mean proportions of whole-hand and index-finger gestures produced for each pointing situation.

Imperative gestures were more frequently associated with whole-hand pointing, whereas declarative gestures, both expressive and informative, were more frequently associated with index-finger pointing (see Table 1 for *t*-tests).

Reciprocally, a significantly higher number of index-finger pointing gestures were produced in declarative situations than in the imperative one, $t(28) = -6.17$; $p < .001$ for declarative expressive pointing and $t(29) = 8.44$; $p < .001$ for declarative informative pointing. Conversely, whole-hand pointing gestures were more frequently used in the imperative situation than in the declarative expressive, $t(28) = 6.48$; $p < .001$, and declarative informative ones, $t(29) = -8.08$; $p < .001$.

Both whole-hand and index-finger gestures were more frequently produced with the right hand than with the left hand, $t(40) = 2.77$; $p < .01$ and $t(41) = 6.78$; $p < .001$. However, when we compared the mean handedness indices (MHI) of children who produced both types of gestures ($N = 34$), whole-hand pointings (MHI = 0.39) tended to be less right-handed than index-finger pointings (MHI = 0.67), $t(34) = -1.74$; $p = .086$.

[1] These included any forms that did not match the earlier description of index-finger or whole-hand pointing gestures (e.g., extending the arm and fist toward an object, without any extended fingers).

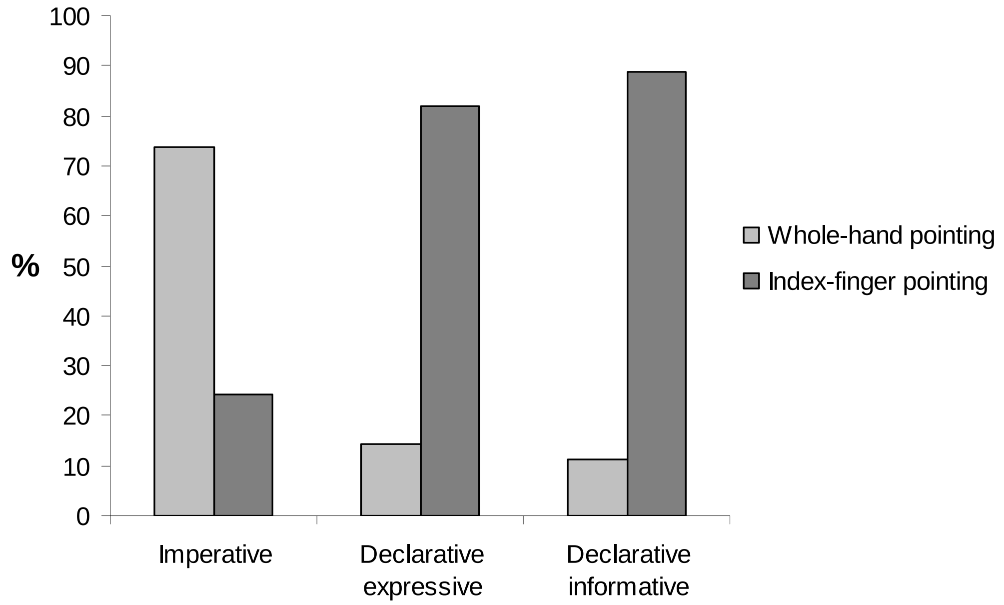

Fig. 1. Mean proportions of whole-hand and index-finger pointing gestures produced in each pointing situation.

Table 1.
Comparison of the mean proportions of whole-hand and index-finger pointing gestures for each gesture function.

	Whole-hand	Index-finger	*T*-test
Imperative pointing	73.6% ± 31.5	24.2% ± 31.9	$t(42) = 7.14$; $p < .001$
Declarative expressive	14.5% ± 32.9	81.9% ± 35.0	$t(30) = -7.70$; $p < .001$
Declarative informative	11.1% ± 26.9	88.9% ± 26.9	$t(33) = -11.75$; $p < .001$

Finally, the proportions of index-finger gestures and whole-hand gestures were correlated with age (r =.58; $p < .001$ and r = -.59; $p < .01$). As they grew older, children produced more index-finger pointing gestures and fewer whole-hand gestures (see Fig. 2). The proportion of index-finger gestures also correlated with language level (r = .41; $p < .01$), as did the proportion of whole-hand gestures (r = -.43; $p < .001$). However, this relation was explained by the correlation between age and language level. After controlling for age, no correlation was found between language level and the proportion of index pointing gestures (for age: $\beta = 0.57$; $p < .01$; for language level: β = 0.059; *ns*).

The correlation between age and gesture form was also investigated for each pointing situation. The same relation was observed for declarative expressive and declarative informative gestures: as children grew older, they produced more index-finger pointing gestures (r =.43; $p < .05$; r =.51; $p < .01$) and fewer whole-hand gestures (r = -.41; $p < .05$; r = - .51; $p < .01$). However, there was no significant correlation between age and the form of imperative gestures (r = .24; *ns* for the proportion of index-finger gestures; r = .25; *ns* for the proportion of whole-hand gestures).

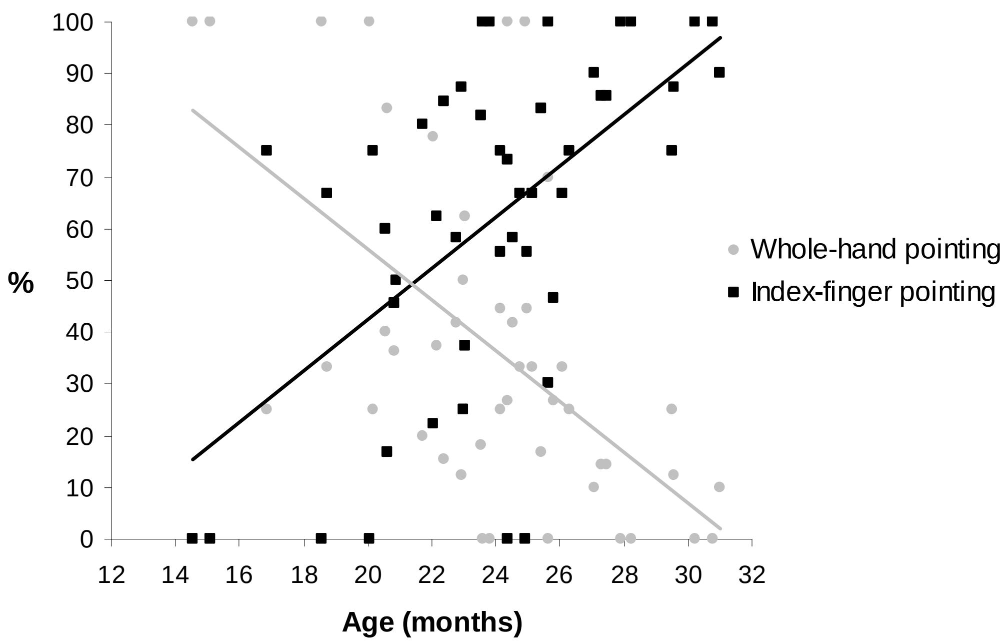

Fig. 2. Proportions of whole-hand and index-finger pointing gestures produced as a function of the children's age.

Handedness

Table 2 and Figure 3 illustrate the mean handedness indices (MHI) associated with the different manual activities we studied.

MHI for reaching actions tended to be lower than MHI for pointing gestures, t(47) = -1.77; p = .079. We then distinguished between the three different pointing situations. In order to compare MHIs, participants who did not produce the two types of pointing involved in the comparison were excluded from the analysis (the number of excluded participants varied for each comparison). There was no difference either between MHI for reaching actions and MHI for imperative pointing, t(42) = -1.01; ns, or between MHI for reaching actions and MHI for declarative expressive pointing, t(30) = -0.62; ns, but MHI for declarative informative pointing tended to be higher than MHI for reaching actions, t(33) = -1.96; p = .054. None of the correlations between MHI for reaching actions and MHI for pointing gestures were significant, whatever situation was considered.

There was no significant difference between MHI for imperative and declarative expressive gestures, t(28) = -0.46; ns, between MHI for imperative and declarative informative gestures, t(29) = -1.54; ns, or between MHI for declarative expressive and declarative informative gestures, t(22) = -0.64; ns. Pearson correlation coefficients confirmed these results, as the MHIs associated with the different pointing gesture situations significantly correlated with each other (imperative and declarative expressive gestures: r = .49; p < .01, imperative and declarative informative gestures: r = .53; p < .01, declarative expressive and declarative informative gestures: r = .58; p < .01).

Lastly, MHIs, whether they were associated with reaching actions or with pointing gestures, were correlated neither with the language test score nor with age.

Table 2.

Mean handedness index (MHI) associated with different manual activities.

	MHI	*SE*	*N*
Reaching actions	**0.32**	0. 10	48
Pointing gestures	**0.55**	0.08	47
Imperative pointing gestures	**0.43**	0.11	42
Declarative expressive gestures	**0.46**	0.13	30
Declarative informative pointing gestures	**0.70**	0.08	33
Whole-hand pointing gestures	**0.37**	0.12	41
Index-finger pointing gestures	**0.62**	0.09	40

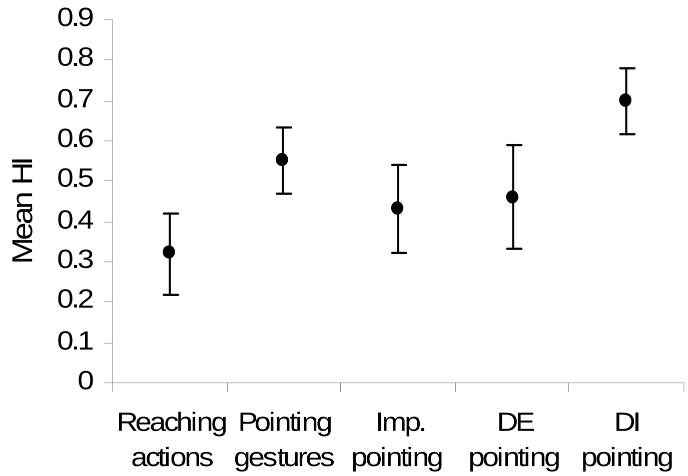

Fig. 3. Mean Handedness Index (± *SE*) associated with reaching actions and pointing gestures (imperative, declarative expressive and declarative informative).

Vocal behavior

On average, 44.2% of the pointing gestures were accompanied by vocalizations (*SD* = 35.1) and 55.8% were not (*SD* = 35.1). The proportion of gestures accompanied by vocalizations tended to be only weakly correlated with language level (r = .30; p = .053), indicating that children with a high language test score did not really vocalize more than children with a lower score. The production of vocalizations seemed to depend more on the type of pointing gesture. In the imperative situation, only 21.1% of the pointing gestures were produced simultaneously with vocalizations, whereas 67.6% and 58.3% of declarative expressive and declarative informative gestures were. Imperative gestures were therefore more frequently produced without vocalizations, *t*(41) = -8.11; *p* < .001. Declarative expressive gestures were more frequently accompanied by vocalizations, *t*(30) = 3.42; *p* < .01, whereas declarative informative gestures were produced with and without vocalizations equally often, *t*(33) = 1.57; *ns*. The mean proportion of declarative gestures accompanied by vocalizations was higher than that of imperative gestures, *t*(28) = -4.14; *p* < .001 for declarative expressive pointing and *t*(28) = -3.35; *p* < .01 for declarative informative pointing. There was no difference between declarative informative and declarative expressive pointing, *t*(22) = 0.77; *ns*.

Visual behavior

Children alternated their gaze between the referent and the experimenter in 20.4% of cases (*SD* = 22.2). They looked solely at the experimenter in 7.4% of cases (*SD* = 12.8) and solely at the referent of the pointing gesture in 72.2% of cases (*SD* = 24.9). We then compared the types of visual behavior associated with the three different pointing situations (see Table 3).

Table 3.
Mean proportions (± *SD*) of the different visual behaviors observed in each pointing situation.

	Referent	Experimenter	Referent/Experimenter alternation
Imperative pointing	86.0% ± 27.4	1.6% ± 7.2	12.4% ± 27.2
Declarative expressive	78.7% ± 27.5	6.1% ± 20.8	15.2% ± 22.8
Declarative informative	44.9% ± 37.86	15.8% ± 25.4	39.3% ± 36.4

The proportion of gaze alternations between referent and experimenter was significantly higher for declarative informative pointing than for imperative pointing, *t*(29) = 2.33; *p* < .05, and declarative expressive pointing, *t*(22) = 3.12; *p* < .01. There was no difference between imperative pointing and declarative expressive pointing for the proportion of gaze alternations, *t*(28) = 0.83; *ns*. The proportion of gazes directed solely at the referent was significantly lower for declarative informative pointing than for imperative pointing, *t*(29) = -3.91; *p* < .001, and declarative expressive pointing, *t*(22) =-3.85; *p* < .001. There was no difference between imperative pointing and declarative expressive pointing, *t*(28) = 1.51; *ns*.

Gesture duration

A majority of gestures lasted less than 1 s (52.8% ± 30.9). However, when we distinguished between the different types of pointing (see Table 4), results revealed that the proportion of gestures lasting less than 1 s only rose above 50% for imperative gestures. Student's *t* tests showed that, for gestures lasting less than 1 s, imperative pointing gestures were significantly more frequent than declarative informative ones, *t*(29) = 2.81; *p* < .01, and tended to be more frequent than declarative expressive ones, *t*(28) = 1.89; *p* = .064. Regarding gestures lasting more than 2 s, declarative expressive and declarative informative pointing gestures were more frequent than imperative ones, *t*(28) = -2.22; *p* < .05 and *t*(29) = -2.80; *p* < .01. There was no difference between declarative informative and declarative expressive pointing, for any gesture duration.

Table 4.
Mean proportions (± *SD*) of pointing gestures according to duration and function

	< 1 s	1-2 s	> 2 s
Imperative pointing	65.7% ± 39.6	25.8% ± 29.6	8.6% ± 19.9
Declarative expressive	46.1% ± 41.6	28.3% ± 31.9	25.6% ± 37.6
Declarative informative	36.8% ± 33.8	35.1% ± 31.2	28.1% ± 27.9

As the experiments were conducted in different testing conditions depending on the daycare center -in isolation versus in a group setting-, analyses of variance were performed for each dependent variable to investigate the potential influence of different environments. These procedural variations were found not to have influenced any of the behaviors we studied. Finally, the results did not reveal any effect of gender on any of the different variables.

Discussion

The aim of the present study was to investigate different types of pointing gesture and to characterize their development in terms of form, duration, gaze, manual laterality and vocalizations. When we focused on gesture duration, hand shape and vocalizations, our results suggested a distinction between imperative and declarative (both expressive and informative) pointing gestures. In terms of handedness and visual behavior, however, imperative and declarative expressive gestures seemed to contrast with declarative informative pointing.

On the whole, declarative pointing gestures were more frequently accompanied by vocalizations than imperative gestures were. Declarative communicative gestures were thus more tightly interconnected with the vocal system than imperative gestures. The facilitative role of gestures in language development may therefore concern declarative rather than imperative pointing, as suggested in previous findings (e.g., Camaioni et al., 2004). It would be interesting to distinguish between different types of vocalizations in order to investigate whether imperative and declarative gestures are characterized by specific vocalizations. For example, whining vocalizations might be associated with imperative gestures, whereas words or pseudowords might be produced more frequently in declarative situations.

Our results revealed that, on average, 44.2% of pointing gestures were accompanied by vocalizations, whereas in another study we conducted of toddlers of about the same age as those in the present sample, 90% of spontaneous pointing gestures were accompanied by vocalizations (Cochet & Vauclair, 2010). However, for the purposes of that study, we deemed that a gesture was accompanied by vocalizations if these occurred within a two-second interval, whereas in the present study, vocalizations and gestures had to be produced at exactly the same time, in order for them to be regarded as simultaneous. Although these different methodological choices probably account for the difference in the proportion of “vocal gestures” between the two studies, the experimental context may also explain this result, as the high percentage of accompanying vocalizations was observed in a natural setting, during free play. The more natural the situation is, the more likely children are to vocalize, and this should be taken into account in developmental studies using experimental designs.

The measure of pointing duration led to another distinction between declarative and imperative gestures: declarative gestures lasted longer than imperative ones, which might reflect infants' wish to maintain interactions in the declarative situation. However, this result is difficult to interpret, as gesture duration depends on a variety of factors, including the time taken by the adult to respond to the child's pointing. For example, if the adult reacted more quickly to a child's request than to a child's comment about a referent, that child might curtail his/her imperative pointing but prolong the declarative gesture. In our study, the experimenter reacted as soon as the children pointed in each of the situations, so the response latencies of the adult to the infants' points were probably equivalent across conditions. But this variable was not recorded and needs to be controlled in future studies before being able to properly interpret our results.

The difference in hand shapes appeared to provide the most persuasive evidence for a distinction between imperative and declarative pointing gestures. Imperative gestures were more frequently associated with whole-hand pointing than with index-finger pointing, whereas declarative gestures, both expressive and informative, were more frequently associated with index-finger pointing. Reciprocally, index-finger pointing gestures were produced more frequently in declarative situations than in the imperative one, while whole-hand pointings were more frequently used in the imperative situation. These results are similar to those reported by Franco and Butterworth (1996) in a study comparing the use of pointing and reaching gestures in 10-18-month-old toddlers, even though they used different terms to describe the gestures. What these authors defined as a pointing gesture (traditional index-finger pointing) was used with a declarative function from the outset, whereas in imperative situations, children produced "reaching" gestures, described by the authors as communicative, open-hand gestures.

Taken together, our results suggest that imperative and declarative pointing gestures emerge from different processes, thus confirming our hypothesis. Imperative pointing appears to originate from non-communicative reaching actions, acquiring a communicative function through a process of ontogenetic ritualization (Tomasello & Call, 1997), as children learn that their gestures produce specific effects on adults. By contrast, imitation would appear to be the learning process involved in the emergence of declarative pointing, as the later was characterized by index extensions in both expressive and informative situations.

The relation between age and gesture form also supports the hypothesis of separate origins for imperative and declarative gestures. As children grew older, they produced an increasing number of index-finger pointing gestures, at the expense of whole-hand gestures, which were used less and less. However, whereas this relation was observed for both expressive and informative types of declarative gestures, the form of imperative gestures did not change as a function of age. Although they were able to use index-finger pointing, children continued to use whole-hand pointing in the imperative situation. This result emphasizes the close relationship between children's objectives and the hand shapes they use: when they are trying to obtain an object, they adopt the hand shape that will allow them to take hold of it. However, this does not mean that imperative pointing is nothing more than the initiation of the grasping action, as many clues, including gaze, posture and vocalizations, attested to the intentional and referential nature of the gesture.

Pointing gestures produced by adults can also take various forms, depending on the situation or the focus of the conversation (Kendon & Versante, 2003; Wilkins, 2003). Nonetheless, the use of pointing gestures by children and adults is quite different: adults' pointing is produced to reinforce the discourse, generally by indicating the referent of a deictic word, whereas infants' pointing is the main component of their communicative signal. Comparing children's and adults' gestures is therefore a delicate matter, and although it seems likely that adults point with all fingers extended when requesting an object, no study so far has actually demonstrated this use of whole-hand pointing gestures in imperative situations.

Moreover, even though the hand shape associated with imperative pointing did not change as the children grew older, there may have been a gradual shift in the underlying cognitive abilities. Social understanding is not an all-or-nothing affair and might indeed involve different levels of understanding (Carpenter et al., 1998). The initial objective of infants' imperative pointing is to influence the adult's behavior. Subsequently, more complex skills develop (in relation to the emergence of declarative pointing) and children's imperative gestures, though still produced to obtain something for themselves, are then probably intended to influence the adult's goals and attention (Liszkowski et al., 2006).

Finally, the distinction between whole-hand and index-finger pointing deserves a more thorough investigation. In the present study, "index-finger gesture" characterized a hand shape in which the index finger was extended and the other fingers either tightly or more lightly curled. It would be interesting to distinguish between the latter to find out whether they are produced in different contexts. Image software would enable measurements to be made of hand shapes on still images extracted from video sequences.

Our results revealed another contrast besides the one between imperative and declarative pointing. With regard to handedness and visual behavior, imperative and declarative expressive pointing seemed to contrast with declarative informative pointing. Gaze alternations between referent and experimenter were significantly more frequent in the declarative informative situation than in the imperative and declarative expressive ones. In the informative situation, the experimenter pretended that she had lost a specific object, which was visible to the children. The latter then pointed toward the object in order to show the adult where it was, indicating that they knew the experimenter lacked this information. Gaze alternation was more frequent in informative pointing because in this situation, children had to establish the relation between the object and the adult and they particularly needed to check the latter's informational state (Liszkowski et al., 2006).

Informative gestures also differed from the other two pointing gestures on hand preference patterns. But before we come to that, we first need to discuss overall results for handedness. Our findings highlighted the difference between manipulative actions and communicative gestures, as none of the correlations between handedness indices (HI) for reaching actions and HI for pointing gestures were significant, whereas HI for the different kinds of pointing gestures all correlated with each other. Moreover, pointing gestures tended to be more right-handed than reaching actions, confirming results of a study by Bates et al. (1986) of 13-28-month-old toddlers.

These results suggest that hand preference for communicative gestures develops independently from handedness for manipulative actions. It has been argued that these different patterns may be related to distinct neurobiological substrates in the left cerebral hemisphere. In particular, Vauclair and Imbault (2009) have postulated the existence of a specific communication system in the left cerebral hemisphere controlling both gestural and vocal communication.

When we distinguished between the different pointing situations, our results showed that hand preference for imperative pointing and declarative expressive pointing did not significantly differ from hand preference for grasping (i.e., manipulative) actions, whereas declarative informative gestures tended to be more right-handed than grasping actions. Moreover, MHI for informative pointing was 0.70, whereas the indices for imperative and expressive gestures were 0.43 and 0.46, figures similar to that reported in the study by Vauclair and Imbault (2009), where MHI for pointing gestures was 0.52. These differences did not reach statistical significance, but this could have been due to the small size of the samples on which the statistical tests were performed (due to some children not producing any pointing gestures in one of the situations).

Thus, overall, our results indicate that the production of informative pointing gestures is particularly lateralized to the left cerebral hemisphere. Although behavioral methods and measures of hand preference only provide an indirect view of brain processes, we can reasonably infer from our results that some specific networks in the left hemisphere are more highly activated in informative situations, possibly reflecting a higher degree of complexity. All pointing gestures were produced in order to direct the addressee's attention toward a referent, but they were used for different purposes in each of the three situations, and may have involved different social-cognitive abilities. The interpretation of infants' social behavior is a tough question, nevertheless, results of several studies (e.g., Camaioni, 1997; Liszkowski et al., 2008; Tomasello et al., 2007) suggest that imperative pointing gestures were produced in order to obtain a desired object, and relied on the child's understanding of the other person as a causal agent. In the declarative expressive situation, children directed the adult's attention to the exciting event with the aim of engaging with the adult and sharing interest in this event. In the declarative informative situation, children pointed because of the adult's relation to the hidden object, implying that they were aware of the adult's informational state. Moreover, informative pointing solely benefited the other person (Liszkowski et al., 2006). These cooperative abilities, which are of a key importance for the emergence of language, may be related to a stronger involvement of the left cerebral hemisphere. Furthermore, informative pointing has been regarded as the first step toward the development of human abilities to teach and instruct other people (Liszkowski, 2005; Warneken, Chen, & Tomasello, 2006).

To summarize, declarative expressive pointing was found to be closer to imperative pointing, regarding visual behavior and hand preference, but closer to declarative informative pointing regarding vocalizations, hand shape and gesture duration. The development of declarative expressive pointing may therefore represent an intermediate stage between imperative and cooperative communication. It may be more complex than simply requesting an object, but less demanding than cooperating with and helping an adult. Moreover, we cannot totally exclude the possibility that declarative expressive gestures were produced with a goal other than sharing interest about a surprising event. It has ever been argued that declarative expressive pointing involved less complex social understanding than usually attributed to infants (e.g., Moore & Corkum, 1994). Southgate, Maanen, and Csibra (2007) have notably argued that these gestures have an interrogative function, that is, children point in order to provoke comments and learn about an event or object, rather than to share enthusiasm about it. In the same way that imperative pointing can be described as a request for an object, declarative expressive pointing may be tantamount to a request for a comment. This hypothesis naturally needs to be tested in experimental investigations, but it could explain the intermediate position of declarative expressive gestures in our results.

Finally, pointing is a complex gesture that is elicited in a variety of situations. The present study highlights the need for researchers to focus on a number of specific features, such as function, hand shape, vocalizations, gaze, and manual laterality, in order to fully investigate and understand this communicative behavior.

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Conclusion

The two studies included in this chapter investigated the production of pointing gestures in naturalistic and experimental contexts, focusing mainly on hand preference, the form and the function of pointing gestures. The differences observed between imperative and declarative gestures, notably in terms of hand shapes and accompanying vocalizations, suggest that different ontogenetic processes are involved in the emergence of imperative and declarative pointing. In both studies, the vast majority of declarative gestures (approximately 90%) were produced with the extended index, and this proportion increased as children grew older, indicating that the few whole-hand declarative gestures recorded were produced by the youngest participants. Although hand shapes constitute only indirect indexes of the origins of pointing, these results support the role of imitation processes in the development of declarative gestures, both expressive and informative. It is still unclear, however, whether imitation processes come into play for all children. It can be hypothesized that children who produced whole-hand declarative gestures learned to use declarative pointing through different processes that still need to be determined. In this perspective, studying the communicative gestures produced by children's caregivers may help to determine to what extent imitation is involved in the emergence of declarative pointing.

As far as imperative pointing is concerned, results of the experimental study (article III) have shown that almost three-quarter of imperative gestures were associated with whole-hand pointing, whereas in the observational study (article II), imperative pointing was characterized equally by index-finger and whole-hand extensions. As mentioned in article II, different forms of imperative gestures might be associated with different degrees of social understanding, the hypothesis being that the proportion of index-finger imperative pointing increases as children develop social and cognitive skills. However, results of the experimental study (article III) did not reveal any significant relationship between age and the form of imperative gestures. Moreover, few children produced a similar number of index-finger and whole-hand imperative gestures, which suggests that the favored hand shape to produce imperative gestures may vary across children, independently of age. It may be useful to carry out studies on older children to find out whether the use of index-finger or whole-hand pointing in imperative situations indeed characterizes one’s gestural repertoire, specific to each individual, or whether the form of imperative gestures depends on contextual features, as suggested by studies conducted on adults (e.g., Kendon & Versante, 2003; Wilkins, 2003). The influence of context, in particular spatial localization, may also explain the different proportions of index-finger and whole-hand imperative gestures recorded in the two studies presented in this chapter. The experimental pointing tasks allowed us to control the distance between the child and the referent pointed at, so that the latter could be similar across children and across conditions. By contrast, this distance was not taken into account in the observational study. Even if we only recorded gestures when the target was positioned centrally in front of the gesturer, children produced both distal and proximal pointing, which may require different degrees of precision and influence hand shapes. This issue therefore will have to be further investigated (see also the general discussion).

The studies described in the present chapter mainly aimed at identifying the features of pointing gestures produced by children in different communicative contexts, but they also focused on the relationship between language and gestures. Results did not reveal any effect of accompanying vocalizations on the degree of hand preference for pointing, and language test score was correlated neither to hand preference nor to the proportion of index-finger pointing. Nevertheless, the lack of significant relationship may be due to the use of cross-sectional designs and/or to the relatively small sample size of the observational study, which is why the relationship between speech acquisition and hand preference for gestures needs to be further examined.

CHAPTER 5. Relationship between hand preference and speech acquisition

5.1. Introduction and aims of article IV

Both structural and functional cerebral asymmetries reported in infants have highlighted the existence of early signs of left-hemisphere specialization for speech processing (e.g., Dehaene-Lambertz et al., 2002; Dubois et al., 2009; Friederici, Friedrich, & Christophe, 2007; Holowka & Petitto, 2002). The right-sided asymmetry for communicative gestures produced by infants and children reflects a left-hemisphere specialization as well, which may be somehow related to language lateralization. Studying the development of hand preference may thus provide some insights into the nature of the speech–gesture links. Specifically, researchers have argued that the cerebral specialization for gestural and verbal signals involves a single communication system in the left hemisphere (e.g., Gentilucci, & Dalla Volta, 2008; Xu et al., 2009).

The studies presented in this chapter intended to test this hypothesis by investigating longitudinally the development of hand preference for pointing gestures, in relation to speech acquisition. These studies were conducted on children between 15 and 25 months of age (article IV) and between 13 and 21 months of age (article V). These age ranges allowed us to study language level from the production of the first words to the first combinations of words into simple sentences. Manipulation tasks were included in order to compare hand preferences for communicative and non-communicative activities during development and examine their respective relationships with speech acquisition. In the first study, children were observed every two months at their homes over a ten-month period.

5.2. Article IV: Cochet, H. (2011). Development of hand preference for object-directed actions and pointing gestures: A longitudinal study between 15 and 25 months of age. *Developmental Psychobiology* (in press).

Development of hand preference for object-directed actions and pointing gestures: A longitudinal study between 15 and 25 months of age

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Abstract

The development of hand preferences for object-directed actions and pointing gestures was investigated in toddlers sampled bimonthly between 15 and 25 months of age. Language level was also assessed, in an attempt to examine the relationship between handedness and language development. Results did not reveal any changes over the study period in the mean handedness index of the whole sample, both for bimanual manipulative activities and pointing gestures. However, the categorization of participants as left-handers, right-handers, or non-lateralized revealed that most of children presented nonlinear individual trajectories in the development of hand preference. Moreover, the only significant correlations observed between hand preferences for manipulation and pointing were negative correlations between the strength of hand preferences at 19 and 21 months of age, suggesting that manipulative actions and communicative gestures are controlled by different networks in the left cerebral hemisphere. These findings are discussed in relation to the development of speech-gesture links in infancy.

Keywords: handedness, bimanual manipulation, pointing gestures, language development

INTRODUCTION

Both speech and gestures are associated with left-hemispheric asymmetries in adults (e.g., Knecht et al., 2000), but the relationship between the emergence of language lateralization and manual asymmetries in infants is still unclear. In an attempt to answer this question, the present study aimed at exploring the relationship between hand preference in different activities and language development in toddlers, over a 10-month period during the second year of life.

It is now widely acknowledged that infants begin to use gestures to communicate before they use words, and the role of gestures in speech development has been highlighted in several studies (see Colonnesi , Stams, Koster, & Noom, 2010). In addition, researchers have shown not only that infants' pointing gestures were predominantly produced with the right hand (e.g., Blake, O'Rourke, & Borzellino, 1994; Cochet & Vauclair, 2010-a; Young, Lock, & Service, 1985), but also that this right-sided asymmetry was stronger than the one reported for noncommunicative manual actions (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986; Cochet & Vauclair, 2010-b; Vauclair & Imbault, 2009). Moreover, laterality for both unimanual and bimanual manipulative actions appears not to be significantly correlated (e.g., Cochet & Vauclair, 2010-c; Esseily, Jacquet, & Fagard, 2011), or to be only weakly correlated with laterality for communicative gestures (Vauclair & Imbault, 2009).

These findings suggest, first, that manual asymmetries for gestures and for manipulative activities follow distinct developmental trajectories in the course of ontogeny. Second, considering both the early signs of left hemisphere specialization for language processing in infants (e.g., Dubois et al., 2009; Friederici, Friedrich, & Christophe, 2007; Mills, Coffey-Corina, & Neville, 1993) and the role of gestures in language learning (e.g., Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004; Goldin-Meadow, 2006), it can be hypothesized that the emergence of manual asymmetries for gestures is linked to the left-hemispheric specialization for language. However, few studies have investigated the development of hand preferences in relation to language acquisition by distinguishing communicative gestures from manipulative actions. Recent research revealed that the frequency of right-handed pointing gestures in 14-month-old infants was correlated to the number of words understood and to the number of words produced, while no significant relation was found between handedness for grasping and language level (Esseily et al., 2011). The relationship between hand preference and language now needs to be investigated throughout development, as this relationship is likely to change at critical periods of speech acquisition (e.g., Bates et al., 1986).

Longitudinal studies also prove to be necessary to compare the strength and stability of hand preferences for noncommunicative activities and communicative gestures across development. Signs of right-sided asymmetries are already expressed in infancy, but the consistency in the degree of hand preference for manipulative activities appears quite limited during the infant's first year of life, especially in unimanual prehension tasks (e.g., Corbetta & Thelen, 1999; McCormick & Maurer, 1988; Ramsay, 1985). Bimanual activities, in which each hand has a specific and different role from the other hand, are now regarded as more reliable measures of handedness, as they require more lateralized patterns of actions (Fagard & Marks, 2000; Fagard & Lockman, 2005). The distinction between active and passive roles for the two hands has been widely exemplified with the *tube* task, in which the non-dominant hand grasps a tube while the dominant hand picks up the object or food inserted in it (e.g., Hopkins et al., 2005; Vauclair & Imbault, 2009). The proportion of right-handed children in bimanual tasks has been reported to increase between 10 and 40 months of age (Vauclair & Imbault, 2009), however, other researchers did not observe any changes in the degree of handedness in both unimanual and bimanual activities between 13 and 28 months (Bates et al., 1986) and between 18 and 36 months of age (Fagard & Marks, 2000). With regard to communicative gestures, findings from several studies focusing on pointing gestures have suggested that the right-sided asymmetry is established in early stages of development. Indeed, the degree of right-hand preference was found to increase between pre-pointing produced at 8 months of age and later pointing produced at 15 months (Young et al., 1985) and 12 months of age (Blake et al., 1994). By contrast, studies with older children did not report any increase in the right-sided bias for pointing between approximately 1 and 3 years of age (Bates et al.., 1986; Cochet & Vauclair, 2010-a; Vauclair & Imbault, 2009).

Overall, these results indicate that the development of hand preference for both bimanual manipulative activities and communicative gestures deserves further investigation. The aim of the present study was to examine the dynamic relationship between language acquisition and hand preferences for bimanual manipulative activities and pointing gestures. Children were followed up every two months between 15 and 25 months of age, in their home. First, we expected to observe different patterns of hand preference between object-directed actions and pointing gestures, in favor of a stronger asymmetry for pointing. Second, we expected the development of hand preference for pointing to be more closely related to language, compared to handedness for manipulation.

METHOD

Participants

Eight French children (four girls and four boys), recruited in daycare centers, were studied every two months in their home with their mother between 15 and 25 months of age. Due to house moving or other family events, two additional children only participated in the first session and were therefore not included in the study. The data were missing for another child at 23 months of age due to illness. Insofar as it concerned only one of the six sessions, this child was not excluded from the study. All children were from middle- to upper-middle-class monolingual French-speaking families.

Procedure

Each session began with a short warming-up period, in the child's bedroom or in the living-room. The language test, two bimanual manipulation tasks and two pointing tasks were then administered in an alternated order across participants. For both manipulative activities and pointing gestures, an attempt was made to administer the same number of trials in each of the two tasks. However, more trials could be administered in one task if children were reluctant to perform the other one. Children were seated either at a child-size table or on the floor, depending on what they were more accustomed to. The experimenter was seated in front of the participants and showed them different objects and pictures. The mother stayed in the room throughout each session, but she was instructed not to initiate interactions with the child and not to point toward the different targets during testing. For the assessment of hand preference, data were only collected when children were sitting in a symmetrical posture, with both hands initially free before starting a trial. All sessions were videotaped.

Language Assessment. The "language" subtest of the French Brunet-Lézine scale (1965) revised by Josse (1997) was used to measure language level. This scale assesses psychomotor development between 2 and 30 months of age. The language subtest comprises a task in which children have to identify familiar objects (N = 10, including for example a spoon and a pair of glasses) and pictures (N = 15, including for example a banana and a bike). Participants either directly name the different items or point toward the objects and pictures designated by the experimenter when they are too young to produce the corresponding words (in the latter case, children had to point to a specific picture among either 6 or 9 different pictures, depending on their age). Other items are based on parental reports (N = 9, for the age range studied), but most of the time, the experimenter could also observe the target behaviour during the session (e.g., knowing whether children use their first name when talking about themselves). Both language production and comprehension are thus assessed, although the total raw score obtained does not allow distinguishing between these different language components. The maximum possible raw score is 73 A developmental age for language is inferred from the raw score via the available French norms. Dividing the developmental age by the chronological age yields a developmental quotient (DQ) for language.

Manipulative Tasks. For both tasks, the hand playing an active role was considered as the dominant hand and the one having a role of support or orientation as the non-dominant hand. In the *bottle* task, children had to hold a small transparent plastic bottle (6 cm in diameter) with their non-dominant hand and take out the stuffed toy that was placed in it with their dominant hand. Five different stuffed toys were used. In the *column* task, children had to remove a plastic ring from a Fisher-Price column with their dominant hand. The experimenter made sure that the ring was pushed down just far enough to require children to hold the base of the column with their non-dominant hand. In total, children undertook between five and ten trials, depending on their willingness to accomplish the tasks.

Pointing Tasks. In the first task, children were asked to point to different pictures (e.g., a ball, an elephant) in a children's book positioned in front of them, either on the table or on the floor. In the second task, children had to point to toys that had been positioned in front of them by the experimenter, at a distance of approximately 1.5 m away. Between five and 15 trials were administered in total, depending on children's willingness to produce pointing gestures. Our initial objective was to perform a number of trials sufficient to record at least eight pointing gestures for each child, without exceeding 15 trials, however, so as to keep the children's attention and interest. Nevertheless, as pointing gestures proved to be relatively difficult to elicit in some children over the study period, we reduced the minimum threshold to five pointing gestures. This number of trials, although limited, is sufficient to reliably assess hand-preference patterns, as indicated by other studies conducted in toddlers (e.g., Cochet & Vauclair, 2010-b; Vauclair & Imbault, 2009). Moreover, Handedness Index scores (see below) for manipulative actions and pointing gestures could still be calculated with a comparable number of responses. The mean numbers of manipulative activities and pointing gestures recorded for each child are displayed in Table 1.

Table 1. Mean Numbers of Bimanual Manipulative Activities and Pointing Gestures (and Standard Deviations) Recorded for Each Child

Participants	Nat.	Cla.	Val.	Ele.	Giu.	Ani.	Jon.	Ada.
Bimanual manipulation	8.17 (.41)	7.5 (1.22)	8.17 (.41)	8.33 (.52)	8.2 (.45)	7.67 (.82)	7.83 (.41)	7.33 (2.07)
Pointing gestures	8.33 (.82)	8.0 (.0)	8.67 (1.03)	8.33 (.82)	8.4 (.68)	8.67 (.47)	9.0 (1.10)	8.0 (1.41)

Data Analyses

An individual Handedness Index score (HI) was calculated for each participant using the formula $(R - L)/(R + L)$, where R and L stand for the total right- and left-hand responses. The HI values lay along a continuum from –1 to 1, with the sign indicating hand-preference direction and the absolute value reflecting hand-preference strength. A Z-score was also calculated using the formula $(R - L)$/ square $(R + L)$ (Fagard & Lemoine, 2006; Michel, Sheu, & Brumley, 2002), in order to classify participants as right-handers ($Z \geq 1.65$), left-handers ($Z \leq 1.65$), or non-lateralized ($-1.65 < Z < 1.65$).

Reliability

The experimenter coded all the sessions from the video recordings. A second coder who was blind to the hypotheses of the study coded 21 % of the total number of sessions (ten sessions were randomly selected). Significant and strong correlations were found between the reliability coding and the main coding for language score, $r = .97$, $p < .01$, handedness score for manipulation $r = .99$, $p < .01$, and hand preference score for pointing, $r = .83$, $p < .01$, thus indicating high level of inter-rater reliability.

RESULTS

Language Development

The mean language scores and the mean developmental quotients were calculated for each session (see Tab. 2). Friedman ANOVA revealed a significant increase in language raw scores between 15 and 25 months of age, χ^2 ($n = 7$; $df = 5$) = 34.9; $p < .001$ (Wilcoxon matched-pairs signed rank tests indicated that all two-by-two adjacent age differences were significant). There was no significant changes in the mean developmental quotient for language between 15 and 25 months of age, χ^2 ($n = 7$; $df = 5$) = 4.31; $p = .51$.

Development of Hand Preference

First, we examined the development of hand preference through the analysis of Mean Handedness Indexes (MHI) of the whole sample (see Tab. 2). Friedman ANOVA did not reveal any changes in hand preference between 15 and 25 months of age, either for manipulative activities, χ^2 ($n = 7$; $df = 5$) = 6.96; $p = .22$, or for pointing gestures, χ^2 ($n = 7$; $df = 5$) = 4.10; $p = .53$.

Table 2. Mean Language Scores, Mean Developmental Quotients, and Mean Handedness Indexes (MHI) for Bimanual Manipulative Activities and Pointing Gestures at Each Age (in Months) Figures in brackets refer to standard deviations.

	15 m	17 m	19 m	21 m	23 m	25 m
Raw score	24.4 (3.8)	31.1 (4.5)	38.8 (6.8)	45.8 (10.6)	58.1 (9.8)	63.8 (10.6)
Developmental quotient	95.1 (14.0)	102.0 (8.2)	103.4 (9.5)	102.7 (14.0)	110.0 (12.6)	107.6 (14.3)
MHI Bimanual manipulation	.78 (.36)	.54 (.47)	.59 (.70)	.21 (.80)	.28 (.65)	.52 (.37)
MHI Pointing gestures	.63 (.23)	.53 (.60)	.50 (.42)	.62 (.55)	.33 (.68)	.51 (.47)

Therefore, in order to provide a global evaluation of infants' hand preference, we calculated single handedness scores for each participant grouping all sessions together. MHI for bimanual manipulation varied between –.41 and 1.0 (M = .49; SD = .46) and MHI for pointing gestures varied between –.19 and 0.86 (M = .53; SD = .35). In the manipulation task, six children were classified as right-handers, one as left-hander and one as non-lateralized. In the pointing task, seven children were classified as right-handers and one child as non-lateralized.

Second, we investigated the stability of hand preference for manipulative activities and pointing gestures focusing on the categorization of children as left-handers, right-handers or non-lateralized over the 10-month period of the study (see Tab. 3). Only one child was strictly right-handed for manipulative activities over the six sessions. With regard to pointing gestures, two children were strictly right-handed over the six sessions. When the classification did not remain stable over the study period, several scenarios were observed, but no clear developmental shifting patterns emerged. Children shifted either once or several times in hand preference, either being first classified as right-handers or non-lateralized. However, it can be noted that no child was classified as left-hander before 19 months of age in the manipulation task, and before 21 months of age in the pointing task.

Table 3. Distribution of Participants as Right-Handers, Left-Handers, or Non-Lateralized for Manipulative Activities and Pointing Gestures as a Function of Age (in Months)

		15 m	17 m	19 m	21 m	23 m	25 m
Manipulative activities	Right-handers	6	3	6	3	2	4
	Left-handers	0	0	1	2	2	0
	Non-lateralized	2	5	1	3	3	4
Pointing gestures	Right-handers	4	5	4	6	3	5
	Left-handers	0	0	0	1	1	1
	Non-lateralized	4	3	4	1	3	2

Relation between Hand Preference for Pointing and Manipulation

Considering the global hand preference scores (i.e., all sessions grouped together), the categorization as right-handers was consistent across the manipulation and pointing tasks for six of the eight children. One child was classified as non-lateralized in both tasks and the last child was classified as right-hander in the pointing task and as left-hander in the manipulation task. There was no significant difference in the MHI for pointing gestures and manipulative activities, Z =.28; p = .78, n = 8, and no significant correlation between these different measures of hand preference, r = .31; p = .46.

Further analyses considering each session separately also failed to reveal any significant differences between MHI for pointing gestures and manipulative activities. Moreover, none of the correlations between the two measures of hand preference was significant, whatever age was considered. However, correlational analyses performed on the absolute values of HI revealed significant negative correlations between the strength of hand preferences for manipulative actions and pointing gestures at 19 months (r = –.79; p = .019) and at 21 months (r = –.87; p = .005).

Furthermore, considering the six sessions separately, the categorization of children as left-handers, right-handers, or non-lateralized was consistent across the two tasks in 21 of the 47 overall observations, including 13 observations where children were right-handed both in the pointing task and the manipulative task, six observations where they were non-lateralized and two observations where they were left-handed.

Relation Between Hand Preference and Language Development

Spearman's correlations were performed to investigate the relation between language level and handedness over development. At 15, 17, 19, 23 and 25 months of age, neither raw language scores nor developmental quotients were correlated to HI for pointing gestures or for manipulative activities. At 21 months of age, results revealed a negative correlation between raw language score and HI for pointing gestures, r = –.73; p = .042, whereas language score was not correlated with HI for manipulative activities, r = .46; p = .25.

Finally, Mann-Whitney *U* tests were used to assess the potential influence of gender on the different variables studied (HI scores and language level), after applying Bonferroni corrections to adjust the level of significance. There was no difference between boys and girls on any of the variables, whatever age was considered.

DISCUSSION

The present study confirmed earlier evidence for the existence of right-sided asymmetries in young children (e.g., Bates et al., 1986; Blake et al., 1994; Cochet & Vauclair, 2010-a, 2010- b; Young et al., 1985), thus demonstrating the preferential involvement of the left cerebral hemisphere both in the control of noncommunicative actions and pointing gestures. Results did not reveal any changes between 15 and 25 months of age in the MHI of the whole sample for bimanual manipulative activities or pointing gestures, in line with several studies with children of comparable age ranges (Bates et al.., 1986; Cochet & Vauclair, 2010-a; Fagard & Marks, 2000; Vauclair & Imbault, 2009). However, we cannot exclude the possibility that bimonthly sampling intervals did not allow us to observe transient and subtle variations of hand preference. For example, Ferre et al. (2010) have shown that developmental changes in the degree of hand preference for object prehension could only be identified using monthly sampling intervals.

Moreover, the calculation of mean indexes tends to mask interindividual variability, whereas the latter needs to be considered in order to identify potentially distinct trajectories in the development of hand preferences. Thus, at the individual level, some children exhibited stable hand-use preferences for bimanual activities and pointing gestures over the ten months of the study, while others presented nonlinear trajectories in handedness development. The classification of participants as left-handers, right-handers or non-lateralized revealed that most of children shifted several times in preference over the study period, but no clear developmental shifting patterns emerged from our results. However, children mainly shifted from right-hander to non-lateralized, or from non-lateralized to right-hander, reflecting fluctuations in the strength rather than in the direction of hand preferences throughout development, both for object manipulation and pointing.

The comparison of hand preferences for noncommunicative actions and pointing gestures did not reveal any significant difference in MHI between the two types of activities, contrary to results of previous studies reporting a stronger right-sided bias for pointing (Bates et al., 1986; Esseily et al., 2011; Vauclair & Imbault, 2009). However, as previously mentioned, MHI does not take into account individual variations during development. Further analyses showed that the two measures of hand preference were not significantly correlated, whatever age was considered, which supports previous findings of studies that examined the relationship between hand preferences for pointing and unimanual reaching (Cochet & Vauclair, 2010-b; Esseily et al., 2011). Moreover, strong negative correlations were observed between the strength of hand preferences (i.e., the absolute values of HI) for manipulative actions and pointing gestures at 19 and 21 months of age, indicating that strongly lateralized children in the pointing task were weakly lateralized in the manipulative task, and conversely. The distinction between left-handed, right-handed and non-lateralized children at each session also showed that the classification was different across both tasks in more than 55 % of observations.

These different developmental trajectories are consistent with the hypothesis according to which a bimodal communication system, specialized for both gestural and vocal communication, is distinct from the system controlling noncommunicative motor functions in the left cerebral hemisphere (e.g., Gentilucci, & Dalla Volta, 2008; Özyürek, Willems, Kita, & Hagoort, 2007; Xu et al., 2009). The fact that the strength of hand preferences varied in opposite directions at 19 months and at 21 months of age might be related to specific periods in speech development likely to influence left hemispheric activity, in particular the lexical spurt period. The lexical spurt is a strong increase in lexical production occurring between 18 and 22 months of age, once children’s vocabulary size reaches about 50 words (e.g., Goldfield & Reznick, 1990; Nazzi & Bertoncini, 2003). A recent study reported that the lexical spurt was accompanied by an increase in the degree of hand preference for pointing gestures, but not for bimanual manipulative activities (Cochet, Jover, & Vauclair, 2011). Therefore, this sudden change in the rate of word learning may be associated with high mobilization of the bimodal communication system in the left cerebral hemisphere, while fewer resources may be attributed to the purely motor system during the same period. In line with this hypothesis, the number of children categorized as right-handers in the pointing task was found to increase between 19 and 21 months of age, while it decreased in the bimanual manipulation task. Although the language test used in the present study did not allow us to determine precisely the onset of the lexical spurt for each participant, these results support the association between increasing lateralization for pointing gestures and increasing productive vocabulary (Cochet et al., 2011; Esseily et al., 2011).

However, several limitations of the present study need to be mentioned. First, the language scale used did not distinguish between language comprehension and production, whereas hand preference might relate in different ways to these different functions. Second, the low number of participants did not allow us to identify common patterns of changes in manual laterality across children, in relation to language development, and restricts the generalization of our findings regarding the relationship between hand preferences for manipulation and pointing at 19 and 21 months of age. Future studies with larger samples and additional measures of language level may shed light on some unexpected results such as the negative correlation between hand preference for pointing and language level at 21 months of age, and should enable to investigate further whether the emergence of manual asymmetries for gestures is linked to the left-hemispheric specialization for speech.

NOTES

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5.3. Aims of article V

Although the study presented in article IV provides some information relevant to understanding the emergence of hand preferences for pointing gestures and manipulative activities, it showed a number of limitations that needed to be addressed in a subsequent study.

First, the language test used assessed several linguistic abilities, but did not allow us to distinguish between language production and comprehension, nor between lexical or syntactic skills. In the following study, we focused on lexical production and assessed the number of words produced by children via a parental questionnaire in order to identify the onset of the lexical spurt. The latter, defined as a major increase in the rate of word learning occurring in the second year of life (e.g., Goldfield & Reznick, 1990; Nelson, 1973), is a key period in language development during which children learn between 4 and 10 new words per day (Bassano, 2000). Children’s productive vocabulary size indeed increases from approximately 60 words at 16 months of age to 300 words at 24 months (Fenson et al., 1993). The lexical spurt may thus be associated with a heavy demand on left-hemisphere resources that may directly influence hand-preference patterns.

Second, this study examined both imperative and declarative pointing gestures, as results of several studies have suggested the existence of different speech–gesture links depending on the function of the gestures (see Chapter 2). Moreover, the study presented in article V was conducted on a larger sample size and children were observed every month over a five-month period. These relatively short intervals may offer further insight into the relationship between speech acquisition and the development of hand preferences for communicative gestures and manipulative activities.

5.4. Article V: Cochet, H., Jover, J., & Vauclair, J. (2011). Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period. *Journal of Experimental Child Psychology* (in press). DOI. 10.1016/j.jecp.2011.04.009

Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period

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Abstract

This study investigated the development of hand preference for bimanual manipulative activities and pointing gestures in toddlers observed longitudinally over a five-month period, in relation to language acquisition. The lexical spurt was found to be accompanied by an increase in the right-sided bias for pointing, but not for manipulation. Moreover, results revealed a significant correlation between hand preference for imperative pointing gestures and manipulative activities in children who did not experience the lexical spurt during the observational period. By contrast, measures of handedness for declarative pointing were never correlated with those of handedness for manipulation. This study illustrates the complex relationship between handedness and language development and emphasizes the need to take the different functions of pointing gestures into account.

Keywords: language development, lexical spurt, handedness, bimanual manipulation, imperative pointing, declarative pointing

A small body of research has described the development of hand preference in relation to language development, although this topic represents a significant source of information for assessing developmental changes of these two main functional asymmetries. Because the use of one hand for a specific activity mostly reflects the predominant involvement of the contralateral hemisphere, this measure provides an innovative means for investigating its relations with the cerebral control of speech during development. Moreover, different measurements of handedness may allow us to determine whether manipulative activities and communicative gestures are linked to speech at varying degrees. In the current study, language level and hand preference for both bimanual manipulation and pointing gestures were measured longitudinally in toddlers between 13 and 21 months of age in an attempt to unravel the complex relationships between language acquisition and the development of handedness. We focused on a key period of language development, namely the lexical spurt, whose onset was expected to be more closely linked to hand preference for pointing than to handedness for non-communicative actions in the course of development. Moreover, speech–gesture relationships were expected to vary depending on the function served by pointing gestures.

Development of handedness: manipulative activities

Although the first signs of asymmetries emerge very early in the infant's development (see Provins, 1992, for a review) and are even already expressed in the fetus (e.g., Hepper, Shahidullah, & White, 1990; Michel, 1981), the degree of hand preference is rather weak and fluctuating during the few months following the first intentional grasping movements, produced at around 5 months of age (e.g., Corbetta & Thelen, 1999; Ramsay, 1985). Bimanual skills, emerging at around 1 year of age, are more likely to reveal stable indicators of handedness than unimanual activities such as reach-to-grasp movements, and this is all the more true as the two hands play much differentiated roles (Fagard & Marks, 2000; Fagard & Lockman, 2005). For these bimanual activities, researchers deem the hand that plays an active role as the dominant hand and the one that is used as a passive support as the non-dominant hand. This can be exemplified with the tube task, in which the non-dominant hand grasps a tube while the dominant hand picks up the object or food inserted in it (e.g., Hopkins, 1995; Vauclair & Imbault, 2009; Vauclair, Meguerditchian, & Hopkins, 2005).

The most important cerebral processes related to the development of handedness are generally thought to take place before 3 years of age, resulting in an increase in the proportion of right-handed children for bimanual manipulative activities (Vauclair & Imbault, 2009). However, another study with children observed at 13, 20 and 28 months of age did not report any increase in the degree of manual asymmetry over this period (Bates, O'Connell, Vaid, Sledge, & Oakes, 1986). Moreover, in assessing hand preference in a unimanual grasping task, Fagard and Marks (2000) observed an increase in the percentage of right-handers between 18 and 36 months of age. By contrast, the percentage of right-handers based on measures obtained from a bimanual coordination task in the same children was not found to vary, suggesting again that bimanual handedness is expressed earlier than unimanual handedness. However, the proportion of right-handed infants generally does not reach the 90% reported for adults (e.g., in infants: Esseily, Jacquet, & Fagard, 2010; Michel, Sheu, Tyler, & Ferre, 2006; in adults: Raymond & Pontier, 2004).

Therefore, although the direction of handedness appears to be stabilized at around 3 years of age, the strength of hand preference is likely to increase in later childhood, until approximately 7 years of age (e.g., McManus et al., 1988).

In addition, methodological differences across studies complicate the issue of handedness development because there is a large variability in the criteria used to categorize individuals as right or left-handers and in the calculation of handedness indexes (see Hopkins, 1999). Thus, the understanding of the development of hand preference still needs to be improved, and longitudinal studies are particularly conducive to investigate this question.

Gestural communication: pointing gestures

Pointing is a referential and intentional communicative gesture that aims at indicating an object, event or location to another person, in a joint attentional frame (e.g., Camaioni, 1993). Pointing first emerges in human infants toward the end of their first year (e.g., Butterworth & Morissette, 1996; Camaioni, Perucchini, Bellagamba, & Colonnesi, 2004) and encompasses various functions and various forms (e.g., Cochet & Vauclair, 2010-a; Tomasello, Carpenter, & Liszkowski, 2007). Researchers have mainly distinguished between imperative and declarative functions (Bates, Camaioni, & Volterra, 1975), with the former being described as a request for a desired object or a specific action on that object and the latter being described as an attempt to direct the adult's attention to a referent in order to indicate its existence and share some interest in it (e.g., Camaioni, 1997). Thus, imperative pointing, at least in its early manifestations, may be regarded as an instrumental act that simply uses the adult as a means to a desired object (e.g., Bates et al., 1975). A few researchers have also argued that declarative pointing is used by infants as a means of gaining positive emotional reactions from the adult rather than to direct the attention of others to external entities (e.g., Moore & Corkum, 1994). However, recent empirical findings, demonstrating that 12-month-old infants were able, first, to point cooperatively to provide information for other persons (e.g., Liszkowski, 2005) and second, to request from adults absent but mutually known objects (e.g., Liszkowski, Schäfer, Carpenter, & Tomasello, 2009), support the hypothesis that both imperative and declarative gestures reveal an early form of psychological understanding of others' mental states.

In addition to a lack of consensus concerning cognitive processes involved in the production of imperative and declarative gestures, it is also unclear whether these two kinds of pointing have distinct developmental trajectories and/or different relationships with speech development. Camaioni et al. (2004) observed that children were able to use imperative pointing earlier than declarative pointing; however, the opposite temporal shift has also been reported (Carpenter, Nagell, & Tomasello, 1998). This discrepancy between studies might be explained by methodological differences because the production of pointing under experimental conditions (Camaioni et al., 2004) may differ from the production of pointing in joint attention episodes between mother and child observed in play situations (Carpenter et al., 1998). An observational study conducted in a day-care center revealed an age-related increase in the proportion of declarative pointing gestures produced by children between 1 and 3 years of age (Cochet & Vauclair, 2010-a), suggesting that children become more likely to declare about events and objects as they grew up. Moreover, declarative communicative gestures have been reported to be more tightly interconnected with the vocal system than are imperative gestures (e.g., Camaioni et al., 2004; Franco & Butterworth, 1996). For example, declarative gestures are more frequently accompanied by vocalizations than are imperative gestures (Cochet & Vauclair, 2010-b). These different relations with speech between imperative and declarative gestures may be reflected in distinct hand preference patterns, as explained in the following section.

Handedness for pointing and language development

Speech–gesture links have been highlighted in many developmental studies, mainly pertaining to the predictive and facilitative effects of gestures on speech development (e.g., Butterworth, 2003; Iverson & Goldin-Meadow, 2005; Pizzuto & Capobianco, 2005; Rowe & Goldin-Meadow, 2009; Tomasello, 2008). Moreover, from a neurobiological perspective, several researchers have postulated the existence of a relation between anatomical and functional hemispheric asymmetries associated with language and hand preference behavior (e.g., Hervé, Crivello, Perchey, Mazoyer, Tzourio-Mazoyer, 2006). Although left hemisphere specialization seems well established in right-handers (e.g., Knecht et al., 2000), relatively little is known concerning the exact nature of this relation, and few data are available in human infants and children. Nonetheless, it has been argued that adult patterns of cerebral asymmetries are set early in infant development (e.g., Amunts, Schmidt-Passos, Schleicher, & Zilles, 1997; Serrien, Ivry, & Swinnen, 2006) and might even develop from processes controlling morphogenesis of the brain in the embryo (Trevarthen, 1996). Moreover, infants have been shown to exhibit left hemisphere lateralization in both speech perception (e.g., Dehaene-Lambertz, Dehaene & Hertz-Pannier, 2002; Mills, Coffey-Corina, & Neville, 1993) and production. For example, a study using near-infrared spectroscopy in a 3-year-old child revealed clear left hemisphere activation in Broca's area during speech production (Gallagher et al., 2007).

Considering these early structural and functional hemispheric asymmetries in the speech-processing cerebral network (see also Dubois et al., 2009), it seems particularly relevant to investigate speech–gesture links through the development of hand preference for communicative gestures. A right-sided asymmetry especially for pointing gestures has been reported in several studies (Bates et al., 1986; Blake, O'Rourke, & Borzellino, 1994; Young, Lock, & Service, 1985; Vauclair & Imbault, 2009). Moreover, Esseily et al. (2011) showed that right-handed infants for pointing understood and produced more words than non right-handed infants, and Vauclair and Cochet (2010) observed a U-shaped relationship in toddlers between 12 and 30 months of age between the degree of hand preference for pointing and the developmental quotient for language. Results from the study by Bates et al. (1986) also support the existence of a dynamic nonlinear relationship between speech and right-hand use: these authors failed to reveal significant correlations between language score and handedness in pointing and symbolic gestures, whereas a nonlinear relationship was observed at 20 months of age.

Thus, although the link between language and hand preference for pointing gesture seems quite obvious, little is currently known about the precise development of this relationship during ontogeny. Thus, a longitudinal study would appear to be appropriate to go some way toward answering this question, especially focusing on a key period of language development occurring during the second year of life, that is, the vocabulary spurt period. The lexical (or vocabulary) spurt is defined by an increase in lexical production occurring toward 18 months of age once children's vocabulary size reaches approximately 50 words (e.g., Goldfield & Reznick, 1990; Nazzi & Bertoncini, 2003). Such a strong increase in the rate of word learning has been suggested to trigger or reinforce the activation of analytical mechanisms (e.g., Locke, 1997) and/or to reflect a fundamental change in the word learning process (e.g., Behrend, 1990; Mervis & Bertrand, 1994). These processes may be associated with a heavy demand placed on left hemisphere resources, which is more likely to highlight the tight interconnection in the brain between speech and communicative gestures. Besides, given the age ranges examined in the different studies mentioned earlier, it appears that a focus on the lexical spurt period may provide some explanations for the nonlinear relationships that were reported between hand preference for pointing and speech development.

In addition, because imperative and declarative pointing gestures seem to relate to speech to different degrees (see above), we may expect declarative pointing to be more right-handed than imperative pointing and/or to be more closely linked with the lexical spurt period. More precisely, hand preference for declarative gestures, but not imperative ones, may develop jointly with the increase in the rate of lexical growth characterizing the vocabulary spurt.

Comparison between communicative gestures and non-communicative activities

Even though studies of hand preference originally pertained to non-communicative object-directed actions, the distinction between communicative gestures and manipulative actions proves to be necessary because the comparison of these two types of activities may reveal different patterns of asymmetry, as well as different relationships with speech development. The right-sided bias has been shown to be stronger for infants' pointing gestures than for manipulative activities regardless of whether it concerns unimanual object grasping or bimanual manipulation (Bates et al., 1986; Cochet & Vauclair, 2010-b). Regarding correlational analyses, Esseily et al. (2011) did not observe any significant relationship between hand preference for pointing gesture and object grasping, although the majority of children were right-handed for both activities. Moreover, Vauclair and Imbault (2009), besides observing a higher number of right-handed participants in pointing than in object manipulation, reported a significant but moderate correlation between handedness scores for pointing gestures and object manipulation. More precisely, the correlation was significant between 18 and 20 months and between 29 and 32 months of age, and it became nonsignificant in the interim, which was interpreted by the authors as reflecting the influence of speech development on hand preference patterns. However, it is difficult to further explain these findings because language level was not directly measured in this study. Finally, few studies have compared hand preference patterns in communicative gestures and manipulative actions, and so far results tend to emphasize some independence between hand preferences for pointing gestures and manipulative activities.

Thus, using a longitudinal design over a five-month period, this study aimed to explore the developmental patterns of handedness for both manipulative activities and pointing gestures during the second year of life, in relation to the lexical spurt period. Another purpose of this study was to examine the difference between imperative and declarative pointing, notably with respect to their relationships with language development.

Method

Participants

A total of 25 French children (13 girls and 12 boys), from Caucasian middle- to upper middle-class families, were studied once a month in day nurseries over a 5-month period. They were between 13 and 17 months of age at the first session. Among these participants, 11 (6 girls and 5 boys) took part in the study in 2008 and 14 (7 girls and 7 boys) took part in the study in 2009 (see Table 1). Children were considered to be 13 months old when their age ranged between 12.5 and 13.5 months and so forth for other ages in months. Parents provided informed consent for their infant's participation.

Because there were slight variations in the manipulation task and in the number of trials per task depending on the year of the experiment (2008 or 2009), we performed Mann-Whitney *U* tests to compare the two groups of children for each variable of interest at each session. There was no significant difference in hand preference scores for either the manipulation task, the imperative pointing task, or the declarative pointing task. Moreover, no significant difference was observed in the language test score. Thus, data from the two groups of participants were combined for statistical analyses.

Table 1
Distribution of participants depending on age at first session and year of experiment.

	13 Months	**14 Months**	**15 Months**	**16 Months**	**17 Months**	**Total**
Number of participants in 2008	0	3	2	5	1	11
Number of participants in 2009	3	3	4	4	0	14
Total	3	6	6	9	1	25

Procedure

Children had met the experimenters before the first day of the experiment to get familiarized with them. Each child was seated at a rectangular table, either in isolation in a separate room or in the main room but apart from the other children depending on the day-care center. One of the experimenters was sitting opposite the child, and the other stood back, noting the recorded behaviors. A bimanual manipulation task and two pointing tasks were administered, with the order of presentation alternated across participants. The two pointing tasks were designed to induce imperative and declarative pointing, respectively, based on earlier studies (Liszkowski et al., 2009; see also Blake et al., 1994, for a description of indicative and request situations). To avoid postural biases, data were recorded only when the child was in a symmetrical position with both hands initially free. Moreover, all the objects and stimuli used were positioned centrally in front of the children. All sessions were videotaped.

Bimanual manipulation. Three variants of a bimanual task were administered, with the hand playing an active role being considered as the dominant hand and the hand having a role of support or orientation being considered as the non-dominant hand. In the "bottle" variant, the child needed to hold a small transparent plastic bottle (6 cm in diameter) with one hand and to take out the soft toy that was placed in it with the dominant hand. In the "sphere" variant, the participant needed to maintain a ball-shaped box (16 cm in diameter) with one hand and to put in a small ball (3.5 cm in diameter) with the dominant hand, or, on the contrary, to take that ball out. In the "column" variant, the child needed to remove a plastic ring from a Fisher-Price column with the dominant hand by holding the base of the column with the other hand. According to the session (2008 or 2009), children performed either three trials of the sphere task and three trials of the column task or four trials of the sphere task and four trials of the bottle task. Thus, in total, children performed between six and eight trials.

Imperative pointing gesture. The experimenter handled attractive toys (e.g., a wind-up ladybird) and showed interest about them, for example by saying, "Look at this! Isn't it funny?" She then put the object on the table, beyond the child's reach (~50 cm away from the child), to induce a pointing gesture. When the child produced a pointing gesture, he or she was given the toy. If the child did not produce any gesture, the trial was considered as ended after approximately 10 s. Children completed three or four trials according to the session (2008 or 2009). A new attractive toy was presented for each trial.

Declarative pointing gesture. For the declarative pointing task, we used piled up cubes, placed at a distance of 50 cm from the child, on which different drawings were stuck (e.g., a dog picture). The experimenter asked the child to show her the different pictures, for example by saying, "Have you seen the dog? Where is it?" When the child produced a pointing gesture, the experimenter commented about the picture. If the child did not produce any gesture, the trial was considered as ended after approximately 10 s. This task aimed at leading children to direct the adult's attention to a picture in order to share some interest about it. Thus, children's gestures were taken into account even if the picture pointed at was different from the one first mentioned by the experimenter. Children performed three or four trials according to the session (2008 or 2009).

Measures

Language. To measure children's language level, parents were asked to fill out the French adaptation (Kern, 2003, 2007) of the MacArthur Communicative Development Inventories (MCDI; Fenson et al., 1993) at every session. For the sake of comparison, we used a simplified version of the "Words and Sentences" questionnaire designed for children between 16 and 30 months of age. Only production was taken into account, with the score obtained corresponding to the total number of words the children had in their vocabulary according to their parents. We removed one aberrant value for a 15-month-old participant because this outlier differed strikingly from the other data and likely resulted from a measurement error.

Hand preference. To assess hand use asymmetries, individual handedness index scores were calculated for each task with the formula $(R – L)/(R + L)$, where R and L stand for the total number of right- and left-hand responses, respectively. Handedness index values lay along a continuum from –1 to 1, with the "±" sign indicating hand preference direction and the absolute value reflecting the strength of hand preference. Handedness indexes were calculated only when children had performed at least two trials.

Missing data. Due to children performing fewer than two trials in the pointing tasks or the manipulation task, or to some parents not always filling out the language questionnaire, some data were missing. The number of observations available depending on children's age and the task are presented in Table 2.

Table 2
Number of observations depending on age and task.

	13 Months	**14 Months**	**15 Months**	**16 Months**	**17 Months**	**18 Months**	**19 Months**	**20 Months**	**21 Months**	**Total**
Language test	2	6	12	18	18	17	13	10	1	97
Bimanual manipulation	1	9	15	22	24	21	15	10	1	117
Imperative pointing	1	7	12	16	22	18	14	7	1	98
Declarative pointing	1	9	13	17	23	21	14	8	1	107

Results

Preliminary Mann-Whitney *U* tests did not reveal any gender effect on either handedness index scores or language test scores.

Cross-sectional analysis

Data were first examined cross-sectionally according to children's age. Because only 3 participants were 13 months old at the first session and only 1 participant was 21 month-old at the last session, we removed these 4 observations and focused on the development between 14 and 20 months of age. The number of observations varied from 6 to 24 depending on the variable and the age considered. Wilcoxon signed ranks tests were used for age-related comparisons of language and handedness scores. Bonferroni corrections were applied to adjust the level of significance for these multiple comparisons ($p < .025$).

Language development. Language scores ranged from 0 to 298 words and, not surprisingly, mean language scores increased between 14 and 20 months of age, as did interindividual variability (see Fig. 1). All the two-by-two adjacent age differences were significant except the one between 14 and 15 months, $Z = 1.6$; $p = .108$; $N = 4$, which was performed on a limited number of children.

Handedness development. Mean handedness indexes (MHIs) associated with bimanual manipulation, imperative pointing gestures, and declarative pointing gestures are displayed in Table 3.

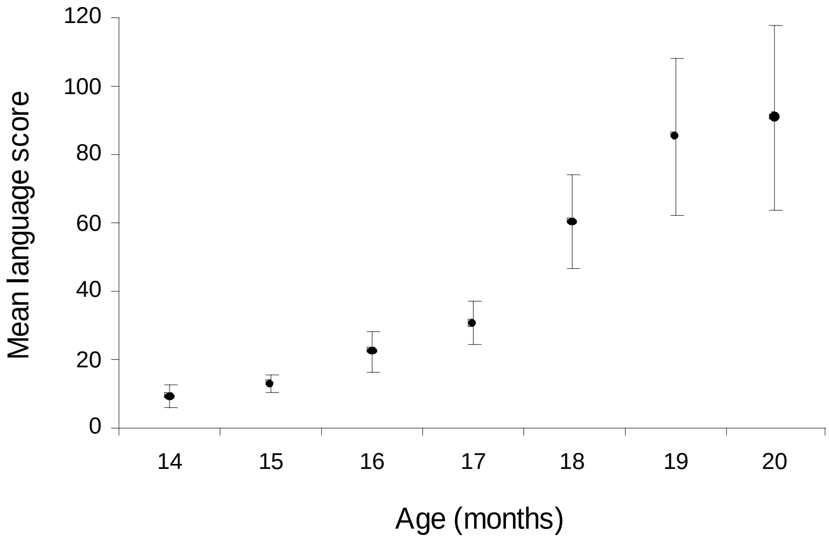

Fig. 1. Changes in mean language scores (± SEs) as a function of age.

Table 3
Mean Handedness Indexes (and SEs) for the different manual activities at each age.

	14 Months	15 Months	16 Months	17 Months	18 Months	19 Months	20 Months
MHI Bimanual manipulation	0.21 (0.23)	0.42 (0.20)	0.52 (0.12)	0.49 (0.098)	0.54 (0.14)	0.39 (0.18)	0.67 (0.14)
MHI Imperative pointing	0.43 (0.37)	0.75 (0.18)	0.81 (0.11)	0.39 (0.17)	0.55 (0.15)	0.76 (0.15)	0.71 (0.29)
MHI Declarative pointing	0.37 (0.16)	0.41 (0.24)	0.77 (0.14)	0.64 (0.12)	0.90 (0.048)	0.73 (0.17)	0.56 (0.29)

Note: Standard errors are in parentheses. MHIs usually vary from –1 to +1; a positive sign reflects right-hand preference, and the absolute value reflects the strength of hand preference.

Two-by-two adjacent age comparisons did not reveal any significant difference in the mean handedness scores for either manipulation or pointing gestures in the course of development. Moreover, the comparison between bimanual manipulation and pointing gestures globally highlighted a stronger degree of hand preference for pointing gestures, although the difference was significant only at 18 months of age for declarative pointing, $Z = 2.24$; $p < .025$; $N = 21$. However, this age-related difference in MHIs remained minor and marginal. Thus, an analysis of handedness as a function of language development appears to be necessary for more significant patterns to emerge.

Handedness and speech development. Spearman rank correlations did not reveal any significant relation between handedness indexes and language scores regardless of what activity and age were considered.

Longitudinal analysis

Subsequently, we investigated the relationship between laterality and language longitudinally, focusing on the lexical spurt period. The following analyses now include all the observations from 13 to 21 months of age.

Handedness and the lexical spurt. To get a descriptive overview of the relationship between handedness and language development, all individual handedness indexes are depicted in scatter plots for the different manual activities. Figs. 2–4 suggest, first, the existence of different relationships between hand preference for manipulation, imperative pointing, and declarative pointing and the total number of words produced, and second, a qualitative change in these relations after the lexical spurt, that is, from the time children attained a 50-word productive vocabulary. Indeed, nearly all data points for which handedness indexes were negative were concentrated before the lexical spurt.

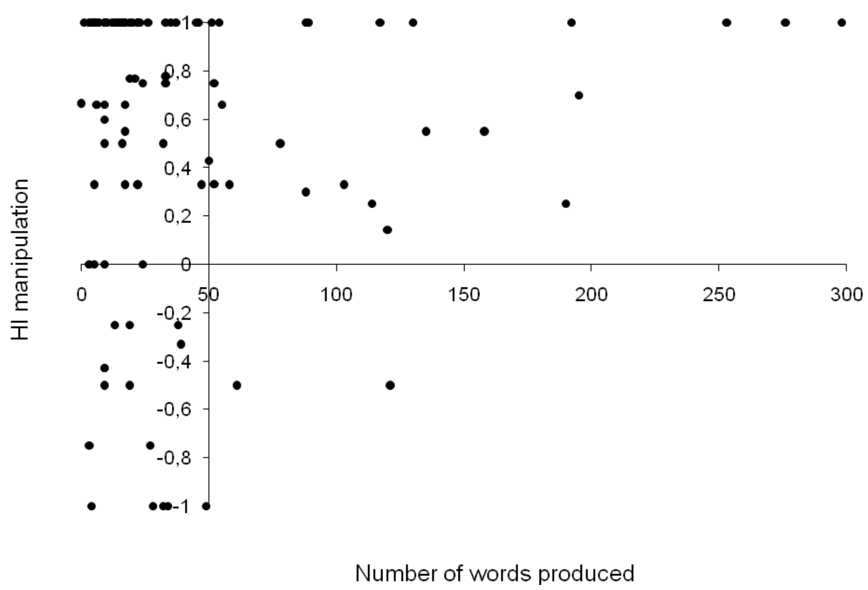

Fig. 2. Scatter plot displaying the relation between language score and handedness for manipulation. HI, handedness index.

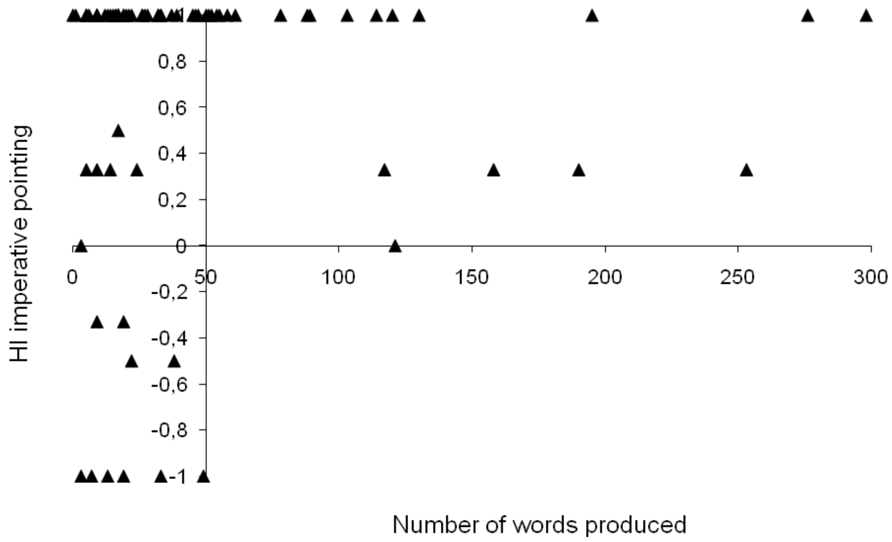

Fig. 3. Scatter plot displaying the relation between language score and hand preference for imperative pointing. HI, handedness index.

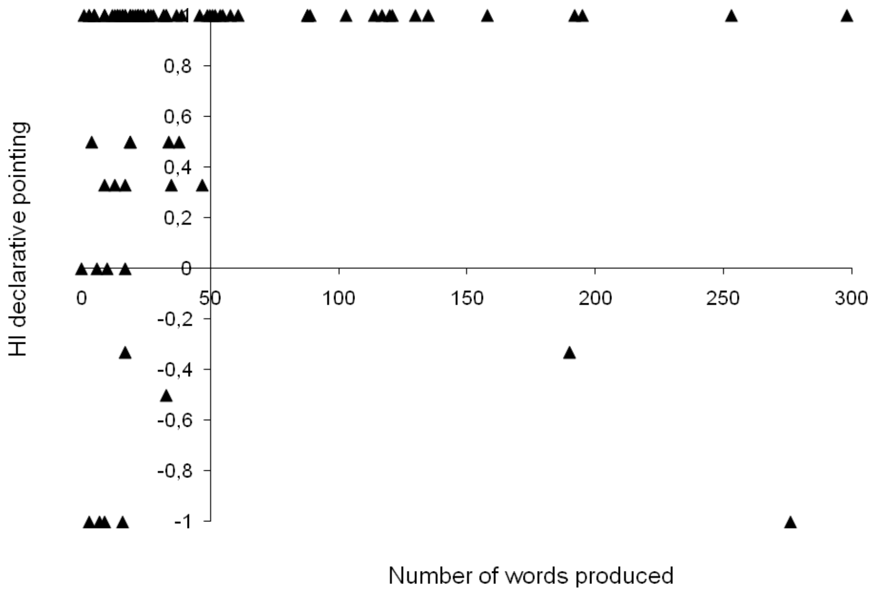

Fig. 4. Scatter plot displaying the relation between language score and hand preference for declarative pointing. HI, handedness index.

Among the 25 participants in the current study, 3 already produced more than 50 words at the time of the first session, 12 did not reach the 50-word threshold associated with the onset of the lexical spurt, and 10 crossed this threshold during the observational period. The youngest children were 16 months old when their lexicon exceeded 50 words and the oldest children were 20 months old (M = 18.1 months; SD = 1.5).

First, Wilcoxon matched-pairs signed ranks tests and Spearman rank correlations were performed to examine the relation between handedness scores before and after the vocabulary spurt for each manual activity. Mean handedness scores, including only the children who reached the 50-word threshold during the observational period, are displayed in Fig. 5. The MHI for imperative pointing gestures tended to be higher after the lexical spurt than before it, $Z = 1.83$; $p = .068$, $N = 9$, and the MHI for declarative pointing was higher after the lexical spurt, $Z = 2.37$; $p < .05$, $N = 9$. There was no difference in MHIs between these two periods for bimanual manipulation, $Z = 0.085$; *ns*, $N = 10$.

Second, we investigated the relationship between handedness scores recorded in the different tasks either before or after the lexical spurt. For the comparisons to be valid (i.e., performed on the same sample of children), analyses included only the participants who reached the 50-word threshold during the observational period ($N = 10$).

Pointing gestures. There was no difference in MHIs between imperative and declarative pointing gestures either before the lexical spurt, $Z = 0.17$; *ns*, or after the lexical spurt, $Z = 0.0$; *ns*. Moreover, handedness indexes for imperative and declarative gestures tended to be significantly correlated before the lexical spurt, $R = .60$; $p = .067$, and were significantly correlated after the lexical spurt, $R = .96$; $p < .001$. These correlations were compared using Fisher's Z transformation (see Raghunathan, Rosenthal, & Rubin, 1996). The correlation between handedness indexes for imperative and declarative gestures proved to be stronger after the lexical spurt, $z = 2.05$; $p < .05$.

Manipulation versus Communication. Before the lexical spurt, MHIs associated with imperative and declarative pointing gestures did not significantly differ from the MHI associated with bimanual manipulation, $Z = 0.21$; *ns*, and $Z = 0.53$; *ns*, respectively. By contrast, after the lexical spurt, the MHI for bimanual manipulation was found to be lower than MHIs associated with imperative and declarative pointing gestures, $Z = 1.99$; $p < .05$, and $Z = 2.02$; $p < .05$, respectively. Moreover, handedness indexes associated with imperative pointing gestures and bimanual manipulation were not significantly correlated either before the lexical spurt, $R = .46$; *ns*, or after the lexical spurt, $R = .44$; *ns*. Similarly, handedness indexes for declarative pointing were not correlated with handedness index for bimanual manipulation either before the lexical spurt, $R = .37$; *ns*, or after the lexical spurt, $R = .41$; *ns*.

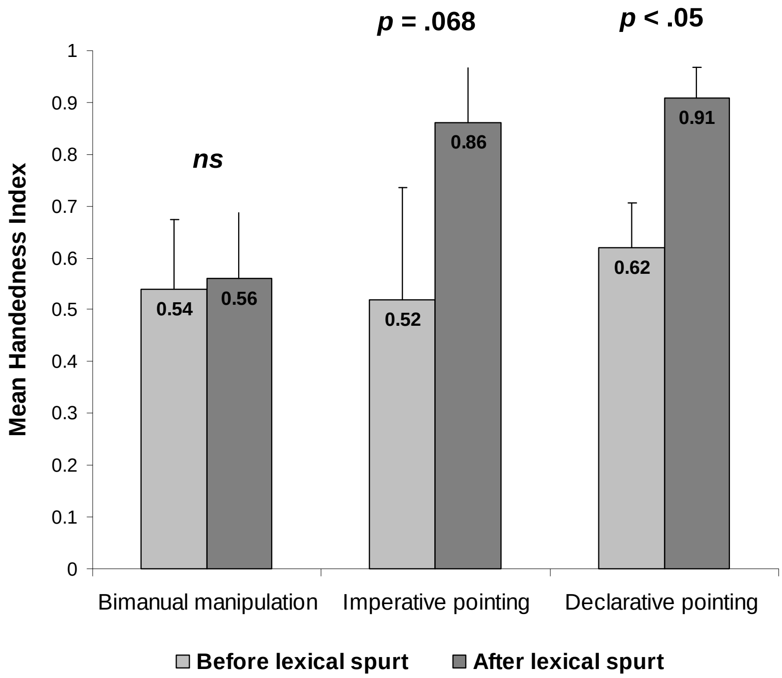

Fig. 5. Mean handedness indexes (±SEs) for the different manual activities before and after the lexical spurt. Mean handedness indexes vary on a continuum from −1 to +1; a positive sign indicates right-hand preference, and the absolute value reflects the strength of hand preference. The level of significance associated with Wilcoxon matched-pairs signed ranks tests is indicated above the bars for each manual activity.

Lastly, the following analyses focused on results obtained in children who did not reach the 50-words threshold (N = 12).

Pointing gestures. There was no significant difference in MHIs between imperative and declarative pointing gestures, Z = 0.36; *ns*. Moreover, handedness indexes for imperative and declarative gestures were not significantly correlated, R = .46; *ns*.

Manipulation versus Communication. MHIs associated with imperative and declarative pointing gestures did not significantly differ from the MHI associated with bimanual manipulation, Z = 1.27; *ns*, N = 22 and Z = 0.36; *ns*, respectively. Moreover, a significant correlation was found between hand preference for imperative gestures and manipulative activities, R = .62; $p < .05$. By contrast, handedness indexes for declarative pointing and bimanual manipulation were not significantly correlated, R = .11; *ns*.

To make sure that the previous results were not due to a general difference in the strength of hand preference between children who experienced the lexical spurt during the observational period and those who did not, we compared MHIs recorded before the lexical spurt between the two samples of children. Mann-Whitney U tests did not reveal any difference between the two groups for either for manipulative actions, U = 45,0; *ns*, or pointing gestures, U = 52,5; *ns* for imperative pointing and U = 59,5; *ns* for declarative pointing.

To summarize, after the lexical spurt, hand preference associated with imperative and declarative pointing gestures was stronger than handedness for bimanual manipulation, whereas there was no difference between these measures before the lexical spurt. Moreover, in children who experienced the lexical spurt during the observational period of the current study, only the correlation between handedness indexes for imperative and declarative pointing was found to be significant. In children who did not experience the lexical spurt, handedness indexes for imperative and declarative gestures were not significantly correlated, whereas a significant correlation was observed between hand preference for imperative pointing gestures and manipulative activities.

Discussion

The main objective of the current study was to investigate the development of hand preference for communicative gestures and manipulative activities in relation to speech acquisition during the second year of life. First, a right-hand preference was observed for both bimanual manipulation and pointing gestures, confirming the results reported in several prior studies (e.g., Bates et al., 1986; Cochet & Vauclair, 2010-a, b; Fagard & Marks, 2000; Vauclair & Imbault, 2009; Young et al., 1985).

Our results did not reveal any overall age-related increase in the right-sided bias for pointing gestures. Previous findings have not reported any strengthening of the right-sided asymmetry for pointing gestures between 13 and 28 months of age (Bates et al.., 1986), between 10 and 40 months of age (Vauclair & Imbault, 2009), and between 12 and 38 months of age (Cochet & Vauclair, 2010-a). By contrast, the degree of right-hand preference was found to augment between pre-pointing produced at 8 months of age and later pointing produced at 15 months (Young et al., 1985) and 12 months of age (Blake et al., 1994), likely reflecting an increasing involvement of the left cerebral hemisphere in the production of communicative gestures. Altogether, these results suggest that the right-sided asymmetry for communicative gestures is already strongly established by approximately one year of age.

Regarding bimanual manipulation, we also did not observe any age-related increase in the right-handed bias, in line with previous results reported in toddlers between 13 and 28 months (Bates et al., 1986) and between 18 and 36 months of age (Fagard & Marks, 2000). Moreover, the overall increase in the proportion of right-handers for bimanual manipulative activities reported by Vauclair and Imbault (2009) was in fact due to a difference observed from 34 months onward. Thus, the strength of handedness may increase during early childhood (e.g., McManus et al., 1988), in a higher age range than the one selected for the current study.

Our results become more telling if we include language development in the picture. Indeed, toddlers' hand preference patterns were found to vary depending on whether or not the lexical spurt had taken place. This specific period in speech acquisition is characterized by a strong increase in the rate of word learning – children learn one or two new words a day – occurring at around 18 months of age. The age of onset of the vocabulary spurt varies sharply across children, but it has also been determined that lexical spurt occurs when the child's productive vocabulary attains 50 words (Benedict, 1979; Goldfield & Reznick, 1990; Nazzi & Bertoncini, 2003; Nelson, 1973). We used this 50-word milestone in the current study to contrast handedness scores as a function of the lexical spurt.

First, the comparison of hand preferences within each manual activity provided further information than the age-related analysis. There was no difference in handedness scores for bimanual manipulation between the two periods (before and after the lexical spurt). By contrast, the degree of hand preference for pointing gestures was found to be higher after the lexical spurt, although the difference was significant only for declarative pointing, whereas it tended to be significant for imperative pointing. Thus, even if a strong right-sided bias for pointing gestures is observed quite precociously, as stated above, this bias strengthens again as the lexical spurt takes place. This result suggests a tight interconnection in the left cerebral hemisphere between speech and communicative gestures, and this is especially true for declarative pointing, which is usually regarded as more closely related to speech development (e.g., Blake, Vitale, Osborne, & Olshansky, 2005; Camaioni et al., 2004; Cochet & Vauclair, 2010-a). Moreover, the increase in the degree of hand preference for pointing reported toward the end of the first year (Blake et al., 1994; Young et al., 1985) might be associated with another important step in speech development that demands a high mobilization of left hemisphere resources, namely the production of the very first words.

The comparison between handedness scores for manipulation and communication also appears more meaningful taking the lexical spurt into account. Before that period, hand preference associated with imperative and declarative pointing gestures did not significantly differ from handedness associated with bimanual manipulation. By contrast, after the lexical spurt, hand preference was stronger for both imperative and declarative pointing than for bimanual manipulation. Moreover, handedness indexes for pointing gestures were not correlated with handedness indexes for bimanual manipulation. On the whole, these findings support the hypothesis of an independence between object manipulation and pointing gestures, associated with the idea that distinct neurobiological substrates in the left cerebral hemisphere control these behaviors (e.g., Vauclair & Imbault, 2009). Considering the interaction between the production of pointing gesture and the lexical spurt, as well as the different functions of pointing, may allow us to clarify and develop this hypothesis.

Before the lexical spurt, the pace of word learning is quite slow and steady. The strong increase in the rate of word learning is likely to be coupled with an increasing involvement of the left cerebral hemisphere in linguistic processes, as suggested by an event-related potential study in 20-month-old infants (Mills et al., 1993). Once this cerebral network has reached a certain level of specialization – with the onset of the lexical spurt – the strength of hand preference for pointing gestures increases up to and exceeding the one for bimanual manipulation. Thus, we can raise the hypotheses that (a) the increasing cerebral specialization involves an integrated and bimodal communication system rather than just speech network and (b) the control of manipulative activities is independent from this communication system. These hypotheses are supported by recent neural evidence reporting simultaneous integration of information from speech and communicative gestures in the brain (Özyürek, Willems, Kita, & Hagoort, 2007; Xu, Gannon, Emmorey, Smith, & Braun, 2009). This left-lateralized and modality-independent system is likely to be located in Broca’s area (Gentilucci & Dalla Volta, 2007).

Interestingly, hand preference scores for imperative pointing were significantly correlated with measures of handedness for object manipulation in children who did not experience the vocabulary spurt, that is, in children who did not reach the 50-word threshold during the observational period. Moreover, among the same children, handedness indexes for imperative and declarative gestures were not significantly correlated. These results, which support the distinction between imperative and declarative gestures, may reflect the more instrumental and object-related nature of imperative pointing (Camaioni, 1997). Children produce imperative pointing to obtain something for themselves, and in their early manifestations, imperative pointing gestures may rely on a child's understanding of the other person as a causal agent. A shift in the cognitive abilities associated with imperative pointing has previously been suggested as children grow older (Tomasello et al., 2007), together with a change in the children's real intention. It was hypothesized that at an early stage, infants aim to influence the adult's behavior, whereas later on, as the adult comes to be regarded as an intentional agent who can decide to help the children, the latter may seek to influence the adult's goals and attention (Cochet & Vauclair, 2010-a). The current study enables us to highlight the period in speech development that is associated with this gradual shift, namely the lexical spurt. In agreement with our interpretation, Nazzi and Bertoncini (2003) proposed that this period corresponds to the onset of the referential use of language resulting from a developmental coupling of linguistic and cognitive abilities. The lexical spurt has also been suggested to be associated with a shift toward more analytical processes (e.g., Behrend, 1990; Locke, 1997; Mervis & Bertrand, 1994). In contrast, McMurray (2007) argued that the lexical spurt was not related to any specialized learning processes, but rather is a by-product of variation in difficulty; that is, the number of words likely to be to learned by children increased with the level of difficulty. The existence of the lexical spurt has also been questioned by some researchers for whom the increase in the rate of word learning is usually more gradual than has been assumed (e.g., Ganger & Brent, 2004). Nonetheless, although the lexical spurt may not occur in all children, or may happen later in some children than in others, a recent study showed that the growth rate of lexical production increased during the second year in most children (e.g., Stolt, Haataja, Lapinleimu, Lehtone, 2008). Beyond the debate on the lexical spurt, the fact remains that in the current study, handedness patterns changed when children reached a certain level of language development (± 50 words).

Contrary to the results concerning imperative gestures, measures of hand preference for declarative gestures were not correlated with those of handedness for manipulation in any of the children's groups. It has previously been argued that declarative pointing, produced with the aim of engaging with the adult and sharing interest in a specific object or event, reflects some infants' understanding of others' psychological states (e.g., Camaioni et al., 2004; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). This early form of social understanding has been demonstrated in 12-month-old infants, when declarative pointing has just emerged (Liszkowski, Carpenter, & Tomasello, 2007), consistent with our results showing that hand preference for declarative pointing is associated from the beginning with hemispheric asymmetries in communicative functions and not with asymmetries in purely motor functions of manipulation.

Thus, our findings suggest that imperative pointing and declarative pointing involve different levels of social understanding during the first few months of the second year of life. However, these gestures, as intentional and communicative signals, remain closely related. There was indeed no difference in the degree of hand preference between imperative and declarative pointing gestures, and these measures were significantly correlated, in line with previously reported results (Cochet & Vauclair, 2010-b). However, this correlation was stronger after the lexical spurt (Spearman's correlation coefficient increased from .60 to .96) and was not significant in children who did not cross the 50-word threshold during the observational period, supporting the hypothesis of a qualitative change of imperative pointing once the lexical spurt has occurred.

Finally, the results of the current study may explain some discrepancies between studies that have shown, on the one hand, significant but moderate correlations between handedness indexes for manipulative actions and pointing gestures (Vauclair & Imbault, 2009) and, on the other, the absence of any significant correlation between these two measures (Cochet & Vauclair, 2010-b). The investigation of hand preference in relation to the occurrence of lexical spurt may have revealed different and finer patterns.

It is also important to mention certain limitations of the current study, most of which are inherent in longitudinal designs. In addition to a relatively small sample size, the numerous missing data did not allow us to use a more analytical approach when analyzing the results (e.g., growth modeling, generalized estimating equation [GEE] analysis). Thus, larger samples should be examined in further research studies, possibly expanding the age range of the children beyond 21 months given that some participants of the current study were probably still too young to experience the lexical spurt.

In conclusion, the investigation of hand preference patterns, even as indirect indexes of hemispheric activity, has highlighted the relation between speech acquisition and declarative pointing gestures. Our results support the existence of a bimodal communication system in the left cerebral hemisphere that is different from the one involved in object manipulation. The present study also emphasized that the production of imperative pointing was associated with this manipulation system during the first months of the second year of life before being more closely related to the communication system with the onset of the lexical spurt. Thus, in future research investigating the relationship between language development and handedness, it appears to be essential to consider the period of the vocabulary spurt and to distinguish between the imperative and declarative functions of pointing.

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Conclusion

Although a right-sided asymmetry for communicative gestures and manipulative activities is already apparent by one year of age, changes in the degree of hand preference showed that this latter is not established in a stable way in the second year of life. The studies presented in this chapter have revealed that the development of right-sided asymmetry is in fact influenced by factors other than age, including the language level. The relationship between speech lateralization and handedness has long been investigated, but the distinction between object manipulation and communicative gestures is not consistently taken into account. Yet, as confirmed by the two studies described in this chapter, hand preferences for manipulative activities and for pointing gestures do not develop in close association, and the link between the lateralization of speech and manual movements is most obvious for communicative gestures.

A study using event-related potentials in 20-month-old infants, categorized as low or high language producers, has revealed that increasing level of language abilities was associated with increasing cerebral specialization for language processing (Mills et al., 1993). In the study presented in article V, increasing language level, which was exemplified through the lexical spurt, was linked to an increase in the right-sided bias for communicative gestures. These results support the hypothesis that communicative gestures and speech are mediated by common neural systems in the left cerebral hemisphere (e.g., Xu et al., 2009). Moreover, the onset of the lexical spurt was not accompanied by any change in handedness for manipulative activities, suggesting that the bimodal system specialized for both gestural and verbal communication is distinct from the one controlling purely motor activities.

The study of both imperative and declarative gestures provides a more complete picture of the relationship between communicative gestures and language. The emergence of hand preference for declarative gestures seems to be associated with language development as soon as children are able to produce declarative pointing, that is, as early as 12 months of age (e.g., Liszkowski et al., 2004), while hand preference for imperative pointing becomes related to the communication system at a later stage, once the lexical spurt has occurred. Our results have thus revealed complex relationships between hand preference and language, which depend on the nature of the manual activity studied – does it involve any communicative intention? – and on the function served by the gestures – are they imperative or declarative gestures?

CHAPTER 6. Hand preferences and communicative gestures in adults

6.1. Introduction and aims of article VI

Handedness in adults has been assessed through a variety of methods and tasks, the most widely used being self-reported handedness questionnaires referring to daily object-directed activities (e.g., Dragovic & Hammond, 2007; Keane, 2008; Van der Elst et al., 2011) and laboratory tasks measuring hand skills in peg-moving or finger-tapping tasks (e.g., Holper Biallas, & Wolf, 2009), or in more complex coordination tasks involving computerized procedures (e.g., Johansson et al., 2006). Moreover, studies investigating patterns of hand preference for communicative gestures have mainly focused on co-speech gestures (e.g., Kimura, 1973; Kita, Condappa, & Mohr, 2007). To our knowledge, there are no data available in adults regarding hand preferences (1) for usual manipulative activities directly performed in natural situations and (2) for communicative gestures other than co-speech gestures.

In the following article, we therefore sought to examine manual asymmetries in a large sample of adult participants for bimanual manipulative activities requiring two qualitatively differentiated manual contributions, and for communicative gestures produced intentionally and referentially, namely pointing gestures. A first objective was to allow the comparison with hand-preferences patterns reported in studies that used similar tasks with children and nonhuman primates. Second, we intended to determine whether hand preferences for communicative gestures and non-communicative activities are as clearly distinct in adults as they are in children. Lastly, in order to investigate the relationship between hand preference and language and test the bimodal communication system hypothesis, we examined the influence of speech on the degree of hand preference by comparing silent and verbal conditions.

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Hand preferences in human adults:

Non-communicative actions versus communicative gestures

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Abstract

Hand preferences for pointing gestures and bimanual manipulative activities were investigated in 127 adult participants. Pointing gestures were produced in two different conditions: a *speech* condition, in which the gestures were accompanied by speech, and a *silent* condition. Although the classification of participants as left- or right-handers, or ambidextrous, was consistent across the manipulation and pointing tasks for 85% of participants, results showed only moderate correlations between handedness scores for bimanual manipulation and pointing gestures. Moreover, results did not reveal any difference in the degree of hand preference between pointing gestures produced along with speech and gestures produced on their own. The implications of these findings are discussed in relation to the lateralization of non-communicative manual actions, communicative gestures and speech.

Keywords: handedness, bimanual manipulation, pointing gestures, speech, lateralization

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1. Introduction

The concept of "handedness" has traditionally referred to manipulative actions, and only a few researchers have investigated manual specialisation for communicative behaviour. Furthermore, although some studies have already undertaken comparisons between manual preferences for manipulation and communication in non-human primates (in chimpanzees: Hopkins et al., 2005; in baboons: Meguerditchian and Vauclair, 2009), as well as in human infants (Bates et al., 1986; Cochet and Vauclair, 2010a; Vauclair and Imbault, 2009), this issue has never been directly addressed in human adults. In an attempt to investigate the relationship between hand preference and lateralization of speech processing, the main purpose of the present study was thus to compare hand-preference patterns for non-communicative actions and communicative gestures in human adults.

1.1. Relationship between hand preference and speech processing

Speech being one of the most striking lateralized functions of the human brain, its relationship with handedness has long been of interest to researchers. In order to investigate this relationship, the nature of the asymmetric actions being performed needs to be taken into account, leading to the distinction between purely manipulative activities and activities involving a communicative intention, that is, communicative gestures. Concerning manipulative actions, the left cerebral hemisphere was shown to be dominant for language in 96% of right-handers and 70% of left-handers (Knecht et al., 2000). This means that the vast majority of left-handed individuals do not have right-hemisphere dominance for speech, demonstrating that the relationship between handedness for manipulative activities and language lateralization is very indirect. For this reason, studying the asymmetries that pertain to communicative behaviour may bring a new perspective to the relationship between hand preference and language processing.

First, behavioural studies have reported a right-sided bias for gestures that spontaneously accompany speech in adults (e.g., Dalby et al., 1980; Kimura, 1973; Saucier and Elias, 2001). Some of these gestures are used intentionally, to refer directly to the speech content (e.g., iconic gestures), but most hand movements are produced to lend continuity, emphasis and rhythm to speech, or else are not clearly connected with its discursive structure (e.g., self-touching movements). Moreover, it has been argued that co-speech gestures are independent of speech production processes (Chu and Kita, 2009). Therefore, in order to examine speech–gesture links and to compare hand-preference patterns for non-communicative actions and communicative gestures, it seems more appropriate to focus on gestures that have the clearest communicative intention. In infants and children, a right-sided asymmetry has been observed for communicative gestures such as pointing gestures and/or symbolic gestures (e.g., Bates et al., 1986; Blake et al., 1994; Cochet and Vauclair, 2010a, 2010b; Vauclair and Imbault, 2009; Young et al., 1985). In deaf adults, a right-sided bias has been reported for signing (e.g., Grossi et al., 1996; Vaid et al., 1989), which may be viewed in relation to neuroimaging data showing that Broca’s area is activated in the production of sign language (e.g., Corina et al., 2003; Emmorey et al., 2007). In hearing adults, one study has reported a right-sided asymmetry for pointing gestures (Bryden et al., 2000), however, the pointing task used in that study did not involve any communicative intention (participants were asked to point to an object indicated by the experimenter, without any specific communicative motive). So for now, no data are available for intentional communicative gestures produced by hearing adults.

Second, studies using event-related potentials and functional imaging have shown that Broca's area is involved in the interaction between words and gestures (e.g., Özyürek et al., 2007; Xu et al., 2009). Moreover, changes in arm kinematics and voice parameters have been reported when symbolic gestures and the corresponding words are simultaneously produced, compared with conditions under which words or gestures are performed on their own (Barbieri et al., 2009; Bernardis and Gentilucci, 2006). Furthermore, neuropsychological studies have revealed that the link between aphasia and apraxia in adults is mainly restricted to ideomotor apraxia, that is, to the reproduction of symbolic and meaningful gestures (see Bates and Dick, 2002).

Altogether, these findings emphasized a tight interconnection in the brain between speech and gesture; nevertheless, neurophysiological and behavioural evidence have suggested that the control of manual actions (which includes both communicative gestures and non-communicative activities) and language processing involves complex cerebral networks (e.g., Gentilucci and Dalla Volta, 2008; Iverson and Thelen, 1999). For example, a functional magnetic resonance imaging (fMRI) study recently reported that the observation of a human right hand grasping an object and the observation of that hand pointing towards the same object result in similar activation of the premotor cortex, an area that plays an important role in coding the observation of manual action (Pierno et al., 2009). By contrast, results of this latter study also suggested different relationships between grasping versus pointing and the cerebral control of speech. Indeed, the comparison of the grasping and control conditions (in the control condition, participants observed a palm-down hand resting next to the object) revealed bilateral differential activity, whereas the differential activation between the pointing and control conditions was confined to the left cerebral hemisphere. Moreover, Gonzales and Goodale (2009) showed that the more participants used their right hand for precision grasping, the more language was lateralized to the left hemisphere, but the rather low correlation value indicated that more complex processes may come into play.

Overall, these results indicate that the cerebral control of communicative behaviours may not be entirely independent of the system involved in purely manipulative activities. The comparison of hand preferences for communicative gestures and object manipulation may therefore improve our understanding of these interactions.

1.2. Comparison between manipulative activities and communicative gestures

In young children, the right-sided asymmetry appears to be stronger for pointing gestures than for manipulative actions (Bates et al., 1986; Vauclair and Imbault, 2009). Signed gestures produced by children born to deaf parents have also been reported to be more right-handed than other manual activities (Bonvillian et al., 1997). A stronger right-handed bias for communicative gestures has been observed in non-human primates as well (in chimpanzees: Hopkins et al., 2005; in baboons: Meguerditchian and Vauclair, 2009). Moreover, correlational analyses in non-human primates and human children have revealed that hand preference for communicative gestures does not significantly correlate with handedness scores for manipulative actions (e.g., Cochet and Vauclair, 2010a), although a weak correlation between these two measures has been reported in toddlers (Vauclair and Imbault, 2009). These different patterns of laterality highlight the absence of a strong relationship between communicative gestures and manipulative actions, which has led researchers to hypothesise that a specific communication system in the left cerebral hemisphere, distinct from the system involved in non-communicative motor activities, may control both gestural and vocal communication, at least in human infants and non-human primates.

In human adults, Bryden et al. (2000) examined hand preferences for different unimanual actions, including grasping and pointing towards small objects in different regions of hemispace. The authors failed to observe any difference in the frequency of right hand use across the different tasks**,** but did not investigate correlations between the tasks. Therefore, the relationship between handedness for manipulative actions and communicative gestures needs to be examined further in adults. From this perspective, it is important to consider the methodological issues related to the study of handedness for manipulative activities, which, as outlined hereafter, may complicate comparisons across studies.

1.3. Handedness for manipulation

Even though researchers seem to agree on a mean percentage of 90% of right-handers in adults (Annett, 1985; Medland et al., 2004; Raymond and Pontier, 2004), the study of handedness for manipulation raises several problems, not least those related to the definition of handedness itself. Handedness is generally defined as the preferred use of one hand for a specific task, regardless of performance, but it can also refer to the hand that is faster and more precise for that task (e.g., Healey et al., 1986). Even if most of the time, people preferentially use their more dexterous hand for a given task, these two definitions may not always perfectly coincide. For example, some people are equally skilled with both hands, but still prefer using one hand rather than the other (see Kraus, 2005). In addition, handedness can be assessed either through self-reported questionnaires, which can be regarded as somewhat subjective, in that they require participants to imagine or recall which hand they use or would use for a given activity, or through direct observation of manual activity.

Moreover, some researchers focus on unimanual manipulations, while others study the coordination of the two hands in bimanual activities, both hands having differentiated roles. This distinction is particularly important, as task complexity has been shown to influence the degree of handedness in both adults and children (Fagard and Lockman, 2005; Fagard and Marks, 2000; Flowers, 1975; Provins and Glencross, 1968), as well as in nonhuman primates (Fagot and Vauclair, 1991). Thus, bimanual manipulative actions seem to induce more lateralized patterns than less challenging tasks, such as simple object grasping.

The final issue concerns the relevance of classifying individuals as left- or right-handers, given that hand preferences are continuously distributed across a spectrum from strongly left-handed to strongly right-handed, and that this categorization relies on different criteria across studies (e.g., Beaton, 2003; Hopkins, 1999).

1.4. Comparison of gesture laterality in speech and silent conditions

Finally, another way of investigating speech–gesture links is to compare the degree of asymmetry between gestures produced simultaneously with speech and gestures produced on their own. Kimura (1973) observed an increase in the frequency of spontaneous right-handed movements during speaking, compared with silent conditions, whereas the occurrence of left-handed movements was not affected. Thus, hand preference was stronger when gestures were accompanied by speech, once again suggesting an association between the control of speech and that of gestures in the left cerebral hemisphere. However, the gestures examined in this study were free movements, defined as "any motion of the limb which did not result in touching of the body or coming to rest" (p. 46), such as waves of the hand. This broad definition may cast doubt upon the intentional and communicative nature of these movements, and we therefore have to ask whether the activation of the speech system affects the laterality of proven intentional gestures (e.g., pointing gestures) in a similar way.

In a bid to answer this question, Lausberg and Kita (2003) asked adult participants to use hand gestures to describe the content of animations showing different movements of geometric objects, either with or without speech. These authors did not report any difference between the silent and speech conditions in the degree of hand preference for iconic gestures. They did, however, observe different distributions of unimanual and bimanual gestures, with unimanual gestures being more frequently produced in the speech condition and bimanual gestures in the silent one. The authors did not distinguish between the activities of the two hands for bimanual gestures, even though they may have had different roles, to the extent that one hand could have been regarded as dominant. The comparison of hand-preference patterns for these two conditions thus does not allow us to draw any further conclusions. In toddlers, Cochet and Vauclair (2010b) found that pointing gestures accompanied by vocalizations were no more right-handed than gestures produced on their own. By contrast, in chimpanzees, Hopkins and Cantero (2003) observed a greater degree of right-handedness when food-begging gestures were accompanied by vocalizations, compared with the same gestures produced on their own.

Accordingly, evidence still need to be collected in human adults to determine whether the left cerebral hemisphere is more highly activated when speech and communicative gestures – intentional and referential – are produced simultaneously.

In the present study, we therefore sought to examine the relationship between hand preference and lateralization of speech processing. We compared the degree of hand preference (1) between pointing gestures and bimanual manipulative activities and (2) between pointing gestures produced on their own and gestures produced along with speech. First, we expected any correlations we found between the degrees of hand preference for pointing gestures and for coordinated bimanual manipulations to be only weak to moderate. Second, we hypothesised that the right bias of pointing gestures accompanied by speech would be stronger than the bias of gestures produced on their own.

2. Method

2.1. Participants

The participants were 127 French university students between 18 and 48 years of age [M = 21.9 years, standard deviation (SD) = 5.8 years], including 56 men and 71 women.

2.2. Procedure and materials

Participants were tested individually in a university experimental room. They were seated at a rectangular table, with the experimenter sitting opposite them. The experiment included a pointing task and a manipulation task, and lasted for a total of approximately 30 min. In order to control their posture, participants were asked to place their hands on the table between each trial, on two symmetrical stickers that had been positioned 25 cm away from the edge of the table. Participants were told that we wanted to study the perception and judgement of different photographs and thus did not know that we were recording hand preferences. They were all informed by e-mail of the real purpose of the study once the data collection was over (we did not inform the participants immediately after the experiment to prevent them from communicating the information to their fellow participants).

2.2.1. Communicative gestures: pointing task. In order to elicit pointing gestures, the experimenter showed participants several photographs and asked them to point to the one they preferred. In order to be sure that the photographs were free of any emotional content that might influence patterns of laterality (e.g., Bourne, 2008; Bryden et al., 1991; Everhart et al., 1996), we selected images of neutral valence from the International Affective Picture System (IAPS; Lang et al., 1999). These IAPS photographs were divided into 30 sets of four photographs. Each set of four photographs (each measuring approximately 8 × 5 cm) was printed on an A4 sheet in a single column. The experimenter placed the sheets one at a time on the table, approximately .6 m away from the participants, so that they had to extend their arms when pointing and could not touch the photographs.

In order to compare the degree of the right-sided bias when both gestural and vocal modalities were involved and when gestures were produced on their own, the trials were administered in two conditions, whose order of presentation was alternated across participants. In the *silent* condition, participants were asked to indicate their favourite photograph through gestures, without saying a word. The experimenter stressed this requirement and reiterated it during the session, when necessary. In the *speech* condition, participants had to express their choice simultaneously gesturally and verbally, and briefly justify their choice as they pointed. Participants were told that these two conditions were set up in order to study the influence of speech on perception. There were 15 trials in each condition.

2.2.2. Manipulative action: bimanual coordination task. Handedness for non-communicative actions was assessed by means of a bimanual coordination task. The experimenter placed a cylinder-shaped container filled with several pieces of paper on the table, in front of the participants. This container was approximately 25 cm tall, meaning that participants had to tilt it with one hand while the other hand grabbed one of the pieces of paper. A number was written on each of these pieces and participants were told that they had to take one to determine the order of image presentation for the second task (pointing task). For example, if a participant picked out a paper on which a three was written, the experimenter showed him or her the third set of photographs. Another number then had to be picked out, and so on, until 30 trials had been performed in each task. Trials for the pointing and manipulation tasks were thus alternated. This procedure allowed us to randomise the sets of photographs and also provided us with a plausible motive for the manipulation task.

2.2.3. Manipulative activities. At the beginning of the experiment, participants filled in a questionnaire about their name, age and e-mail address, which allowed the experimenter to record the hand used for writing. Additional measures of hand preference for manipulative activities were collected through a hand-preference questionnaire, which was sent by e-mail to the participants at the end of all the experiments. Eighty-three participants (i.e., 65.4% of the sample) answered the questionnaire. This questionnaire contained 13 items extracted from the Edinburgh Handedness Inventory (Oldfield, 1971), including one item about handwriting. The latter confirmed the results obtained from direct observation during the experiment, for all the participants who answered the questionnaire.

2.3. Data analyses

An individual handedness index score (HI) was calculated for each participant and for the different tasks using the formula (R–L)/(R+L), where R and L stood for the total right- and left-hand responses. The HI values lay along a continuum from –1 to 1, with the sign indicating the direction of hand preference and the absolute value (AbsHI) characterising the strength of hand preference. For the bimanual task, the hand that played an active role, that is, that grabbed the piece of paper, was considered as the dominant hand and the one having a supporting role, that is, tilting the container, as the non-dominant hand. This distinction between active and passive roles for the two hands has been widely used in studies with human infants or non-human primates, for example with the *tube* task, in which the non-dominant hand grasps a tube while the dominant hand picks up the object or food inserted in it (e.g., Hopkins et al., 2005; Vauclair & Imbault, 2009).

Moreover, binomial tests performed for each individual, indicating whether the use of the left and right hands significantly differed, enabled us to classify participants as left-handed, right-handed or ambidextrous in each task. Given that all participants performed the same number of trials, we calculated the number of left- and right-hand responses allowing this classification, the level of significance being set at .05. For the manipulation task, individuals were considered left- or right-handed if they performed at least 20 of the 30 trials with the left or the right hand (respectively), and as ambidextrous if the number of right-hand responses varied between 11 and 19. For the handedness questionnaire, participants were considered left- or right-handed if they answered that they used their left or right hand (respectively) for at least 10 of the 13 items, and as ambidextrous if the number of right-hand responses varied between 4 and 9. Last, for the pointing tasks, participants were classified as left- or right-handers if they performed at least 11 of the 15 trials with the left or the right hand (respectively), and as ambidextrous if the number of right-hand responses varied between 5 and 10.

3. Results

3.1. Hand preference: descriptive results

3.1.1. Bimanual manipulation. For the coordinated bimanual task, 111 participants were right-handed (87.4%), 12 were left-handed (9.4%) and four were ambidextrous

(3.2%). Mean HI was .76 (SD = .59) and mean AbsHI was .94 (SD = .18).

3.1.2. Handedness questionnaire. Of the 83 participants who answered the questionnaire, 71 were right-handed (85.54%), seven left-handed (8.44%) and five ambidextrous (6.02%). Mean HI was .73 (SD = .52) and mean AbsHI was .88 (SD = .17). Handedness scores measured with this questionnaire were not correlated with the HI obtained from the coordinated bimanual task (r = .11; *ns*). However, when we distinguished between right-handed, left-handed and ambidextrous participants (on the basis of handedness scores on the bimanual manipulation task), a significant correlation was observed between these two measures in right-handed individuals (r = .39; p < .001). There was no significant correlation in left-handed participants (r = .33; *ns*), and there were too few ambidextrous individuals for us to perform the correlation.

3.1.3. Pointing gestures. For the pointing task in the *silent* condition, 103 participants were right-handed (81.1%), 16 were left-handed (12.6%) and eight were ambidextrous (6.3%). Mean HI was .68 (SD = .64) and mean AbsHI was .91 (SD = .22). For the pointing task in the *speech* condition, 98 participants were right-handed (77.2%), 13 were left-handed (10.2%) and 16 were ambidextrous (12.6%). Mean HI was .65 (SD = .62) and mean AbsHI was .85 (SD = .28).

These descriptive results, as well as the mean number of right-hand responses for each activity, are summarized in Table 1.

Table 1. Mean number of right-hand responses (±SD), mean HI (±SD) and mean AbsHI (±SD) for the different activities.
Mean HI usually varies from –1 to 1. The positive sign here reflects right-hand preference and the absolute values indicate the strength of hand preference within the group of participants.

	Bimanual manipulation (30 trials)	**Handedness questionnaire** (13 items)	**Pointing (*silent* condition)** (15 trials)	**Pointing (*speech* condition)** (15 trials)
Mean number of right-hand responses	26.39 (±8.85)	10.73 (±3.68)	12.59 (±4.83)	12.10 (±4.70)
Mean HI	.76 (±.59)	.73 (±.52)	.68 (±.64)	.65 (±.62)
Mean AbsHI	.94 (±.18)	.88 (±.17)	.91 (±.22)	.85 (±.28)

3.2. Comparison of hand-preference patterns for bimanual manipulation and pointing gestures

There was no significant difference between pointing gestures produced on their own, that is, in the *silent* condition, and bimanual manipulative actions, either for mean HI, $t(127) = 1.57$; *ns*, or for mean AbsHI, characterising hand-preference strength, $t(127) = 1.68$; *ns*. HIs for these two measures were significantly correlated (r = .56; $p < .001$ for HI and r = .36; $p < .001$ for AbsHI). By contrast, pointing gestures produced with speech were less right-handed than bimanual manipulative actions, $t(127) = 2.55$; $p < .05$. The strength of handedness was also greater for manipulative actions, $t(127) = 4.46$; $p < .001$. HIs for these two measures were significantly correlated (r = .65; $p < .001$ for HI and r = .55; $p < .001$ for AbsHI). Comparison of these correlations using Steiger's (1980) t-test revealed that HI for bimanual manipulation was more strongly correlated with HI for pointing in the *speech* condition than with HI for pointing in the *silent* condition, $t = 2.65$; $p < .01$.

Categorical analyses were also performed, based on the number of individuals classified as right-handed, left-handed and ambidextrous regarding bimanual manipulative actions and pointing gestures in the *silent* condition[2] (see Table 2). Handedness patterns were consistent across the two different tasks for 85% of the participants, including 77.1% who were right-handed for both the pointing task and the coordinated bimanual task, 7.1% who were left-handed and .8% who were ambidextrous.

However, the distinction between right- and left-handers regarding the manipulation task actually revealed an absence of any significant correlation between hand preferences for pointing and manipulation (in right-handers, r = .059; *ns* and in left-handers, r = .26; *ns*). The distinction between right- and left-handers regarding the pointing task led to similar results (in right-handers, r = .13; *ns* and in left-handers, r = .23; *ns*), indicating that the significant correlation between pointing gestures and bimanual manipulation described earlier should be interpreted with caution.

Moreover, as shown in Figs. 1 and 2, mean HI for pointing was .80 (SD = .49) in right-handers for manipulation and –.47 (SD = .79) in left-handers for manipulation. Conversely, mean HI for bimanual manipulation was .91 (SD = .34) in right-handers for pointing and –.11 (SD = 100) in left-handers for pointing. The number of ambidextrous participants was too small for us to perform these analyses.

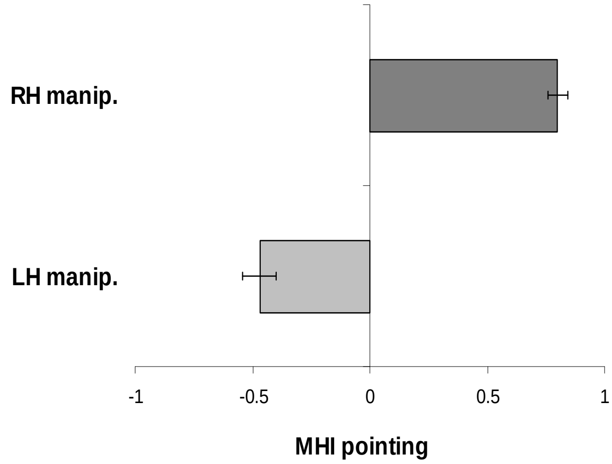

Fig. 1 – Mean HI (±SE) for pointing gestures in right- (RH) and left-handers (LH) for bimanual manipulation.

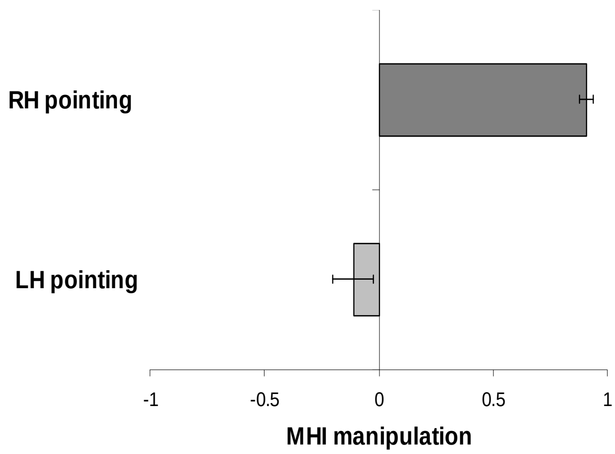

Fig. 2 – Mean HI (±SE) for bimanual manipulation in right- (RH) and left-handers (LH) for pointing gestures.

[2] It seemed more relevant to focus on the condition involving the gestural modality alone, rather than on the bimodal condition, to differentiate between right-handers, left-handers and ambidextrous individuals.

Table 2 – Distribution of right-handed, left-handed and ambidextrous participants for pointing gestures (in the *silent* condition) and bimanual manipulation.

		Manipulation			
		Right-handed	Left-handed	Ambidextrous	Total
Pointing	Right-handed	98	2	3	103
	Left-handed	7	9	0	16
	Ambidextrous	6	1	1	8
	Total	111	12	4	127

3.3. Comparison of hand preferences for pointing in the silent and speech conditions

Overall, pointing gestures accompanied with speech were not more right-handed than pointing gestures produced on their own, $t(127) = 1.23$; *ns*. HIs for these two variables were significantly correlated ($r = .88$; $p < .001$). By contrast, when we focused on the strength of hand preference (i.e., AbsHI), the latter appeared to be greater for gestures produced on their own than for gestures produced along with speech, $t(127) = 2.64$; $p < .01$. Pearson's correlation was also significant for AbsHI ($r = .50$; $p < .001$).

Moreover, the correlations between HIs for gestures produced along with speech and gestures produced on their own were significant in right-handers (with respect to hand-preference scores for pointing in the *silent* condition, $r = .54$; $p < .001$), but not in left-handers ($r = -.07$; *ns*) or ambidextrous individuals ($r = .23$; *ns*).

Finally, the results did not reveal any effect of gender on handedness scores, regardless of whether they were associated with bimanual manipulation, $F(1, 125) = .12$; *ns*, or with pointing gestures in either the *silent* condition, $F(1, 125) = 3.70$; *ns*, or the *speech* one, $F(1, 125) = 1.49$; *ns*.

4. Discussion

In the present study, handedness was assessed in a large sample of adults, through direct observation of hand use and also via a questionnaire. The main objective was to compare the degrees of hand preference for non-communicative actions (bimanual manipulation) and communicative gestures (pointing).

More than 87% of participants were right-handed for manipulation, in line with several studies reporting approximately 90% of right-handers among human adults (Annett, 1985; Raymond and Pontier, 2004). A strong majority of participants were also classified as right-handers for pointing gestures (approximately 81% in the *silent* condition and 77% in the *speech* condition). There was no significant difference in the mean HIs between pointing gestures produced on their own and bimanual manipulative actions, whereas pointing gestures produced along with speech were found to be less right-handed than bimanual manipulative actions. Thus, contrary to our initial hypothesis, lateralization of communicative gestures was no more robust than lateralization of non-communicative motor actions, and was actually weaker when gestures were accompanied by speech. Moreover, overall results revealed significant, but moderate, correlations between handedness scores for pointing and for manipulation (the percentage of variance explained varied between 31% and 42%, depending on the condition). However, further analyses that distinguished between right- and left-handers failed to reveal any significant correlations between hand preferences for pointing and manipulation.

Until now, the relationship between handedness patterns for gestures and non-communicative actions had not been directly investigated in human adults. As a consequence, no parallels can be drawn with other studies. Nevertheless, it may be useful to compare these findings with results of studies conducted in non-human primates and in human infants, at least with those that have used similar tasks and similar indexes to assess handedness. Mean HIs observed in the present study for manipulative activities were much stronger than the mean HIs that have been reported for non-human primates (in chimpanzees: Hopkins et al., 2005; in baboons: Meguerditchian and Vauclair, 2009) and for human children (e.g., Cochet and Vauclair, 2010a). For instance, measures of handedness in toddlers between 10 and 40 months of age have revealed a mean HI of .32 (Vauclair and Imbault, 2009), while the mean HI observed in the present study reached .76. The degree of hand preference for manipulative actions therefore continues to increase strongly throughout the course of development, and not solely in infants and toddlers, as previously indicated by a study in children between 3 and 9 years of age (McManus et al., 1988).

Regarding communicative gestures, the degree of hand preference observed in the participants of the present study was also stronger than in non-human primates (Hopkins et al., 2005; Meguerditchian and Vauclair, 2009), although this comparison needs to be viewed with some caution, as the continuity between communicative gestures produced by non-human primates (e.g., food beg and hand slap gestures) and humans is still subject to debate (e.g., Gomez, 2005; Pika, 2008).

Moreover, hand preference for pointing gestures does not appear to differ strongly between children and adults (e.g., Vauclair and Imbault, 2009). The mean HIs reported for spontaneous pointing gestures (.68; Cochet and Vauclair, 2010b) and informative pointing in toddlers (.70, Cochet and Vauclair, 2010a) are similar to the mean HIs observed in the present study (.68 and .65 in the *silent* and *speech* conditions, respectively). Therefore, under certain circumstances, adults and children aged approximately 1–3 years present an equivalent degree of left-hemisphere dominance in the production of communicative gestures, and overall, the difference in the distribution of hand-preference patterns between adults and infants is greater for object manipulation than for pointing gestures. These results indicate that hand preference for pointing gestures is established earlier in development than handedness for manipulative actions, thus suggesting that object manipulation is an unlikely basis for the emergence of right-handedness in humans. Moreover, the strong right-sided asymmetry reported for informative pointing in young children – an asymmetry comparable to the one observed in adults in the present study – suggests that cooperative abilities may play an important part in the development of a left-lateralized system of communication (Cochet and Vauclair, 2010a).

As previously stated, our results revealed moderate correlations between measures of handedness for pointing and manipulation, but these correlations proved not to be significant when right- and left-handers were considered separately. At a more general level, the categorization of participants as right- or left-handers for bimanual manipulation was not entirely independent of the categorization for pointing gestures. Here again, the contrast with non-human primates and human infants may help us to interpret these results and improve our understanding of issues related to the origins of handedness and human language. In non-human primates, researchers have shown that hand preferences for gestures are not significantly correlated with hand use for manipulative actions, whether these actions concern unimanual reaching or bimanual manipulation (in chimpanzees: Meguerditchian, Vauclair, and Hopkins, 2010; in baboons: Meguerditchian and Vauclair, 2009), whereas handedness scores for different communicative gestures are significantly correlated with each other (hand slap and food beg gestures). In children, studies have also failed to reveal any significant correlation between hand preferences for pointing gestures and handedness scores for manipulative actions (e.g., Cochet and Vauclair, 2010a; Cochet et al., in press), although one study did report a weak correlation between these two measures, explaining 15% of the variance (Vauclair and Imbault, 2009).

Hand preferences for communicative gestures and for non-communicative activities are thus quite independent in human infants and in nonhuman primates, whereas these two variables seem, to some extent, to be related in adults (although hand choices for these different activities do not perfectly coincide). This interconnection is supported by the results of an fMRI study, showing that the observation and production of communicative gestures and object-directed movements activate the mirror neuron system to a similar degree (Montgomery et al., 2007).

To summarize, hand preference for communicative gestures appears to be established in early development, whereas the increase in the degree of handedness for object manipulation seems to occur later in childhood. Language lateralization may thus initially be associated with the asymmetry of communicative gestures, with the gradual development of interactions between the cerebral control of speech, gestures and manipulative activities resulting in complex intertwined networks in human adults.

The second objective of the present study was to find out whether pointing gestures produced along with speech were more right-handed than gestures produced on their own. Results did not confirm our hypothesis, failing to reveal any overall difference in the degree of right-sided asymmetry for pointing gestures between the *speech* and *silent* conditions. We had expected pointing gestures accompanied by speech to be more right-handed than gestures produced on their own, given that the control of speech and gesture in the left cerebral hemisphere is mediated by very close, and possibly similar, neurobiological substrates (e.g., Bernardis and Gentilucci, 2006; Gentilucci and Dalla Volta, 2008; Xu et al., 2009). At first glance, one might thus interpret these findings as reflecting bilateral control of speech in our participants, and with hindsight, it would have been helpful to directly measure cerebral lateralization for speech, for example with a dichotic listening task. However, this bilateral hypothesis appears unlikely, as it is well acknowledged that the majority of people, even left-handers, have left-hemisphere dominance for language processing (e.g., Knecht et al., 2000), and the relatively large sample of the present study enables us to rule out the possibility of any sampling bias.

The fact that the “strengthening” effect of vocalizations on hand choice for communicative gestures has been demonstrated in chimpanzees (Hopkins and Cantero, 2003) offers several possible explanations for the results of the present study. First, the difference between ape vocalizations and human speech suggests that we should focus on the potential effect of discourse content on handedness patterns. It has been argued that the nature of the task, and more specifically the involvement of verbal versus spatial abilities, can influence asymmetries in hand use (e.g., Hampson and Kimura, 1984). However, a consistent degree of right-hand preference has been reported for co-speech gestures, whether speakers are talking about verbal, spatial or neutral topics (Lavergne and Kimura, 1987), thus ruling out any effect of speech content on hand preference for gestures. In addition, in the present study, we can reasonably consider that the tasks were not complex enough to involve any problem-solving system that might interfere with handedness patterns. The manipulation task did not require any specific spatial ability, while in the pointing task, participants were simply asked to designate their favourite photograph, either simultaneously through speech and pointing gesture or solely through gesture. Moreover, the experimenter made sure that it was not difficult for the participants to briefly justify their choice in the *speech* condition (the latter were told that they did not have to provide any explanation if they did not know why they preferred a particular photograph).

Second, we cannot exclude the possibility that the participants, while inhibiting speech production in the *silent* condition, generated internal language when they chose and pointed towards a specific picture. Although the pattern of cerebral activation associated with internal speech would need to be investigated, this hypothesis might explain the equivalent degree of right-hand bias between pointing gestures produced on their own and gestures produced along with speech.

Finally, a simple explanation for the absence of any difference in the degree of asymmetry for pointing gestures between the *speech* and *silent* conditions would be that the right-sided asymmetry observed in human adults is already too strongly marked (much more so than in chimpanzees) for subtle differences in the intensity of activation of the relevant cerebral areas to increase it any further.

However, when we focused on the strength of hand preference (i.e., AbsHI), the right-sided asymmetry was found to be stronger for gestures produced in the *silent* condition than for gestures produced in the *speech* one. This result, while unexpected, does not necessarily invalidate the underlying hypothesis that a communication system in the left cerebral hemisphere controls both gestural and vocal communication, as hand-preference scores in the two conditions were still significantly correlated. However, this finding deserves further investigation. For example, participants may have produced co-speech gestures with their dominant hand in the *speech* condition. This would leave only their non-dominant hand free for pointing, leading to a stronger right-sided asymmetry in the *silent* condition. However, there are no data available so far demonstrating a greater bias for co-speech gestures than for pointing gestures in adults. Another future direction for research pertains to the different functions of gestural communication. When pointing gestures were produced on their own, they “shouldered” the full burden of communication, whereas they served more as props when they were produced along with speech, the latter playing the leading role. This difference has already been reported in adults: when participants are asked to communicate solely with their hands, their gestures take on the segmentation and combination properties characteristic of speech (Goldin-Meadow, 2006). In infants, a study using event-related potentials has highlighted developmental changes in the processing of gestures in the course of the second year (Sheehan et al., 2007). This study has revealed that common cerebral mechanisms initially underlie the mapping process for words and gestures, whereas subsequently, as children acquire language and no longer use gestures primarily as referential labels, words and gestures elicit distinct patterns of brain activity. Cerebral processes appear thus to be influenced by the role served by gestures, which, returning to the present study, further supports the hypothesis that the greater strength of hand preference for pointing in the *silent* condition is explained by the "language-like form" of gestures.

Moreover, results revealed significant correlations between hand-preference indexes for pointing gestures in the *speech* and *silent* conditions for right-handers (based on hand-preference scores for pointing in the *silent* condition), but not for left-handers or ambidextrous individuals. Lateralization of both pointing gestures and speech appears thus to be closely linked in right-handers for pointing, whereas patterns of functional asymmetries are less clearcut in other individuals, who are more likely to have either right-hemisphere language dominance or little lateralized specialisation.

Finally, handedness scores obtained from the questionnaire did not correlate with those obtained with the coordinated bimanual task. Further analyses revealed a significant, but moderate, correlation in right-handers only, reflecting less clearly lateralized patterns in left-handed and ambidextrous participants. Other studies have also reported weak correlations (explaining less than 25% of the variance) between self-reported measures of handedness and more direct task-oriented measures (e.g., Bryden et al., 2000; Cavill and Bryden, 2003). It has been argued that these two methods may assess different aspects of hand preference, the hypothesis being that the questionnaire data reflect a more cognitive component (e.g., implying memory processes) and direct observation of hand use an immediate motor component (Cavill and Bryden, 2003).

The absence of a strong correlation between these two indexes emphasizes the importance of methodological choices in measuring hand-preference patterns. Therefore, researchers need to be aware of the differences between self-reported measures and direct observation of hand preference, as well as of the influence of the activity they select. For example, most of the items in the Edinburgh Inventory refer to unimanual activities (e.g., using a toothbrush or hitting a nail with a hammer), whereas the task administered in the present study required the coordination of both hands, which may also explain the different degrees of right-hand bias we recorded.

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Conclusion

The study presented in this chapter provides information relevant to the understanding of the relationship between hand preferences for communicative gestures and non-communicative activities in adults. It is important to note that hand preferences were assessed in natural situations through tasks eliciting a commonly used gesture and familiar object manipulations, contrary to the complex experimental tasks generally used with adult participants to measure hand performance (e.g., Johansson et al., 2006). This study thus offers a reliable assessment of manual asymmetries in adult population for different activities, based on tasks that have been previously used in studies with young children (e.g., Esseily et al., 2010; Fagard & Marks, 2000) and nonhuman primates (e.g., Hopkins et al., 2011; Vauclair et al., 2005). Besides, the comparison of hand-preference patterns between children and adults and between human and nonhuman primates may improve our understanding of the ontogenetic and phylogenetic processes involved in the emergence of speech-gestures links, in relation to hemispheric lateralization.

However, several issues need to be addressed to go one step further in interpreting the results of this study. For example, additional measures of handedness for manipulative activities may have been useful to determine precisely which factors influence the degree of manual asymmetry, and in particular to identify why handedness scores recorded in the bimanual task and with the self-reported questionnaire were not strongly correlated. Future studies may thus consider including several manipulation tasks in which participants would directly perform both unimanual (e.g., using a key to unlock a door) and differentiated bimanual familiar activities (e.g., dealing cards). Similarly, it may be useful to asses hand preference for communicative gestures other than pointing gestures, such as co-speech gestures and symbolic gestures frequently used in social interactions (e.g., waving goodbye).

Moreover, the comparison of hand preferences for pointing in the speech and the silent conditions, which yielded unexpected results, also deserves further investigation. Several hypotheses have been raised to explain the absence of any difference between these conditions, but for now, we cannot favor one hypothesis over the other. However, special emphasis should be put on the content of the verbal discourse produced along with gestures. A study has recently shown significant decrease in the right-hand preference for depictive co-speech gestures representing actions when adult participants were asked to explain metaphorical meanings, compared to non-metaphor conditions (Kita et al., 2007). In the study presented here, the participants indicated to the experimenter their favorite photograph and briefly justified their choice. The nature of these explanations, likely to vary across individuals, might have influenced the respective contributions of the left and right cerebral hemispheres, and therefore hand-preference patterns. Thus, investigating speech–gesture links in adults demands a close examination of the complex use of spoken language to find out whether the left-hemisphere dominance for communicative gestures and language involves one and the same communication system.

CHAPTER 7. General discussion

By examining gestural communication and hand preference in human infants and children, the present work has provided a fruitful approach to studying the development of human communication and cerebral asymmetries. The first part of this discussion will summarize the main results obtained and discuss them in relation to their implications for child development, the evolutionary origins of language and neuroimaging literature. The second part will deal with the methodological issues associated with the study of language development and hand preference, and the last part will present some directions that would particularly need to be considered for future research.

7.1. Summary of the main results

7.1.1. Language acquisition and hand preferences

Investigating patterns of hand preference in children and adults by making a distinction between communicative gestures and manipulative activities opens a unique window onto the cerebral organization that underlies the close relationship between gestures and language. First of all, the studies presented in this dissertation have confirmed the existence of a strong right-sided bias in the production of communicative gestures. Although these studies (articles II–V) did not reveal any age-related increase in the degree of manual asymmetry between approximately 1 and 3 years of age, the development of hand preference for pointing gestures was found to follow nonlinear trajectories, which were associated with high interindividual variability (article IV). In addition, the comparison between manipulative actions and communicative gestures has provided evidence for the existence of two distinct systems in the left cerebral hemisphere, namely a bimodal communication system and a motor system controlling non-communicative manual activities. Studies conducted on children revealed indeed a stronger right-hand preference for pointing gestures than for object manipulation (articles III and V), as well as an absence of significant positive correlations (articles III and

V) and even negative correlations (article IV) between these different measures of hand preference.

The hypothesis of different neural networks controlling communicative behaviors and manipulative actions was further supported by a look at the lexical spurt period. The onset of this period, characterized by an increase in the rate of word learning, was accompanied by an increase in the right-sided asymmetry of pointing gestures, whereas we did not observe any changes in handedness for bimanual manipulation. These results may reflect the maturation of control mechanisms in the left cerebral hemisphere, mechanisms that appear to involve a common substrate for language and communicative gestures.

Moreover, in order to bring additional evidence of the close relationship between communicative gestures and language acquisition, I have examined the influence of vocalizations (article II) and speech (article VI) on hand preference for pointing gestures. The comparison of hand preference for gestures produced alone and produced simultaneously with vocal signals did not yield any significant results, nor did the search for correlations between language level and hand preference indexes (articles III, IV and V).

However, a thorough analysis of the different functions of pointing gestures has provided a more complete picture of the speech–gesture links and of the processes of hemispheric specialization. The study of several behavioral markers has highlighted some differences between imperative and declarative gestures. Declarative gestures were more frequently accompanied by vocalizations and more frequently characterized by index-finger gestures than imperative gestures (articles II and III). Furthermore, measures of hand preference for declarative pointing were never found to be correlated with those of handedness for manipulation. By contrast, a significant correlation was observed between hand preferences for imperative pointing and object manipulation in children who did not experience the lexical spurt during the observational period of the study, namely in children who were less advanced in language development (article V).

Altogether, these results indicate that imperative and declarative gestures may develop from different processes and may be associated with different abilities. Declarative pointing seems to be closely linked to language development from early stages. Imitative processes, which have been suggested to play a role in language acquisition (e.g., Arbib, 2005a; Tomasello, 2008) may therefore also be involved in the emergence of declarative pointing. Moreover, the use of declarative gestures may be associated with the development of social and cognitive abilities related to the understanding of others' knowledge and intentions. This understanding has been reported to develop over the second and third years of life (e.g., Bellagamba, Camaioni, & Colonnesi, 2006; Carpenter, Call, & Tomasello, 2002; Kawakami et al., 2011; Southgate, Chevallier, & Csibra, 2010), a period of time during which the spontaneous production of declarative gestures was found to increase (article II). It is important to note though that the relationship between gestures and the construction of social-cognitive skills may be bidirectional. Some abilities emerging during the first year of life, such as shared attention, gaze following, deferred imitation and turn-taking influence the production of communicative gestures (e.g., Carpenter et al., 1998; Heimann et al., 2006), which in turn promotes interactions and gradually enables children to further understand the mental states that precede and motivate others' behaviors (e.g., Meltzoff, 1995).

This may be particularly true for declarative informative pointing (Tomasello et al., 2007), which was more frequently associated with gaze alternation between the communicative partner and the referent than imperative and declarative expressive pointing (article III). Gaze alternation being regarded as one of the markers of intentional communication (e.g., Franco & Butterworth, 1996), informative pointing must be closely related to the development of communicative skills, especially to the development of cooperation abilities (e.g., Liszkowski et al., 2006). Moreover, the difference in the degree of hand preference between manipulative actions and pointing gestures was found to be the strongest for informative pointing, which suggests an important role of such cooperative gestures in the cerebral lateralization of communicative behaviors.

In contrast to declarative pointing, imperative pointing appears to be a more instrumental gesture, primarily used to satisfy physical needs. More frequently characterized by whole-hand extensions, imperative gestures may originate from non-communicative reaching actions and involve only the understanding of communicative partners as actors (e.g., Liszkowski & Tomasello, 2011). However, our results have highlighted a qualitative change of imperative pointing in relation to language development. Once the lexical spurt has occurred, the production of imperative pointing is no longer related to object manipulation and may therefore be associated with more sophisticated social-cognitive skills, similar to those involved in the production of declarative pointing. The importance of the lexical spurt in this developmental change is supported by results of another study showing negative correlations between the strength of hand preferences for manipulative actions and pointing gestures at 19 and 21 months of age (article IV). Although productive vocabulary size was not assessed in this study, this period of time, which seems to require a strong mobilization of the bimodal communication system, might correspond to the lexical spurt. Moreover, as imperative pointing was characterized both by index-finger and whole-hand gestures (article II), one may wonder whether the qualitative shift for imperative gestures described above is accompanied by a change in hand shapes. Actually, our results did not reveal any significant correlation between age and the form of imperative gestures (article III), suggesting that hand shapes remain influenced by the communicative situation as children grow older. Studies examining communicative gestures produced by adults strengthen this hypothesis, as hand shapes were reported to vary according to the communicative context and to the nature of the information being conveyed (e.g., Enfield, Kita, & De Ruiter, 2007; Kendon & Versante, 2003; Wilkins, 2003).

The distinction between imperative and declarative gestures may contribute to a better understanding of the complex relationships between the control of speech, gestures and actions. Indeed, the influence of manual actions on vocalizations has been demonstrated both when infants between 11 and 13 months of age manipulated objects and when they produced request gestures – corresponding in that study to imperative pointing – towards the same objects (Bernardis et al., 2008). At first sight, these findings seem to go against the hypothesis that gestural and verbal communication and non-communicative object manipulation are controlled by two distinct systems in the left cerebral hemisphere, but they may in fact reflect the link between early use of imperative gestures and manipulative actions. The contrast between communicative gestures and non-communicative activities may intensify during development, especially with the onset of the lexical spurt (article V).

However, results of the study conducted on adults have revealed that hand preferences for pointing gestures and bimanual manipulative actions were related to a stronger extent than what was observed in children (article VI), suggesting the existence in adults of an entangled left-lateralized network controlling both communicative signals and non-communicative actions. This hypothesis, which is also supported by neuroimaging studies (see below), implies that the left-hemisphere specialization for communicative behaviors, initially involving speech and gestures, may gradually become associated with asymmetries in manipulative actions as children grow up. Thus, handedness for object manipulation may develop more slowly and over a longer period of time than hand preference for communicative gestures. Although it is quite difficult to pinpoint the exact chronological sequence governing the emergence of hand preference for manipulative actions and communicative gestures – especially because asymmetries in the production of intentional gestures cannot be assessed until the end of the first year – the hypothesis of different developmental rates in the emergence of hand preferences is supported by several results. First, there is a greater right-sided bias in young children for communicative gestures than for manipulative actions (Bates et al., 1986; Bonvillian et al., 1997; Vauclair & Imbault, 2009; and see articles III and V of the present work). Second, patterns of hand preference recorded in children and adults differ more strongly for object manipulation than for pointing gestures (see article VI). Through the increased frequency and complexity of manipulative activities during childhood, handedness for non-communicative actions eventually reaches a strong degree of right-sided bias in adulthood.

In parallel, the role of communicative gestures in the processes of hemispheric specialization may undergo a shift in the course of development that might result in some reorganizations of the relationship between speech, gestures and actions. Event-related potential (ERP) measures in 18 and 26 month-old children have supported the existence of a developmental change in the relationship between speech and gestures. Common neural mechanisms were shown to initially underlie the processing of words and gestures, but as children acquire speech and no longer use gestures as primary signals, the semantic processing of words and gestures seem to elicit different patterns of cerebral activation (Sheehan et al., 2007). These findings can be related to experiments made in adults that revealed different features of gestures depending on whether they were used as the sole communication modality or as a secondary modality supporting speech (Goldin-Meadow, 2006).

To sum up, the lateralization processes associated with the production of communicative gestures and language may precede those associated with manipulative actions. In early stages, left-hemisphere specialization may thus particularly involve the processing of speech and gestures and gradually integrate from the third year of life the control of manipulative activities. Therefore, we argue that left-hemisphere dominance for communicative behaviors and for non-communicative manipulative actions, although they are not independent phenomena, represents two distinct facets of brain lateralization. This hypothetical scenario has been supported by studies examining the relationship between language lateralization and handedness for object manipulation in adults, which have reported weak to moderate correlations between these measures (Bryden, Singh, Steenhuis, & Clarkson, 1994; Gonzalez & Goodale, 2009; Knecht et al., 2000, and see article VI). Moreover, the use of different methods to assess handedness has yielded discrepant findings. Using a dichotic listening task to measure language lateralization, Bryden et al. (1994) showed that the difference in the right-ear advantage between left-handers and right-handers was only significant when the classification was based on scores obtained on an unskilled handedness factor, derived from a preference inventory. In addition, correlations were found to be significant for activities such as flipping a coin and striking a match, but not for other activities such as writing and throwing a ball. Thus, further investigations are still needed to unravel the complex mechanisms involved in the relationship between handedness for object manipulation and language lateralization.

7.1.2. Implications for developmental psychology

Gestures constitute a privileged means of communicating intentionally before the emergence of speech and the numerous studies presented throughout this dissertation have demonstrated that they contribute significantly to language acquisition. In particular, pointing gesture has been regarded as “a stepping-stone” to language development (e.g., Colonnesi et al., 2010; Goldin-Meadow, 2007), notably because its age of onset and its frequency of use appear to be related to the number of words understood and produced by children (e.g., Jacquet et al., 2011).

The production of gestures, which is carried over into the linguistic period (e.g., Guidetti, 2005; Stefanini et al., 2009), may also play a more general role in shaping human communication. Early gesture use has even been suggested to predict the development of social-emotional concepts (Vallotton & Ayoub, 2010). However, it should be noted that the nature of the mental processes associated with infants' communicative gestures is still subject to debate (e.g., Leavens, 2009) and contrasting views of early social cognition (see also Lewis & Carpendale, 2002) may have implications for the study of the relationship between gestures and the development of social and cognitive abilities. With this in mind, we postulate that pointing gestures, and especially declarative gestures, are involved in the development of complex communicative skills, allowing children to understand others' intentions and interact with them in various and complex ways. Research conducted by Goldin-Meadow (2003) has emphasized the role of gestures in learning processes, showing for example that children were more likely to succeed in mathematical equivalence problems when they used a problem-solving strategy in gestures (Cook & Goldin-Meadow, 2006). Interestingly, children benefiting from the production of gestures were those who had previously observed the experimenter using this strategy.

Thus, caregivers' communicative gestures can facilitate children's learning through imitation processes, raising the question of the place of gestures in educational environments. Not only are children's gestures regarded by developmental psychologists as valuable indicators of later language development (e.g., Crais, Watson, & Baranek, 2009), but they can also be used to directly enhance children's communicative skills. Although this question needs to be cautiously dealt with to prevent any misuse, parents and teachers might consider using gestures and encouraging children to produce gestures in order to promote speech acquisition and the development of more general abilities. Researchers have been studying the effects of pre-linguistic interventions, in particular in children with language delays or developmental disorders (e.g., McCathren, 2000; Warren, 2000). Overall, interventions approaches have proved to be beneficial to the development of children's later communicative skills, but effectiveness has been defined by a number of different dimensions and few studies have been conducted with large samples and over long periods of time (see Warren, Fey, & Yoder, 2007).

The present work has also provided information pertaining to the development of hand preferences, which may be useful to understand the processes of brain lateralization. This question is important as hemispheric specialization may be crucial to the development of complex abilities, for example to the mastery of fine motor skills. Moreover, the fundamental role of hemispheric asymmetries has been highlighted by studies reporting atypical patterns of manual asymmetries in individuals suffering from a wide range of disorders, from dyslexia and stuttering to more severe pathologies such as autism and schizophrenia (e.g., Eglinton & Annett, 1994; Lewin, Kohen, & Mathew, 1993; Somers, Sommer, Boks, & Kahn, 2009). Thus, results of the present work, suggesting that left-hemisphere specialization initially involves communicative behaviors, may provide researchers with a relevant direction to consider in order to identify the origins of inconsistent hemispheric lateralization.

7.1.3. The question of language origins

Understanding the mechanisms by which the complex structure of language emerged and developed is of key importance for understanding human evolution and may therefore contribute to change the way we consider the human species, which may explain scientists' keen interest in the question of language origins. Involving a number of disciplines such as anthropology, linguistics, neuroscience, archaeology, developmental psychology, and primatology, this question has indeed been capturing the attention of researchers for years.

The present work has highlighted the existence in young children of a left-lateralized system controlling both gestural and vocal communication. This system has been hypothesized to have a deep phylogenetic origin (e.g., Corballis, 2010; Locke, 2007). Thus, the primacy of gestures observed in human infants in the emergence of intentional communication and manual asymmetries may parallel the evolutionary scenario that led to the emergence of human language. Investigations of communicative behaviors in our nearest primate relatives provide some arguments in support of this hypothesis. Whereas nonhuman primates' vocal displays convey mostly emotionally-based information in response to specific situations, gestural communication has been reported to share several properties with human language (e.g., Meguerditchian et al., 2011). Great apes' communicative gestures meet the criteria of intentional communication (e.g., Leavens et al., 2005, and see Chapter 1) and they are used in a much more flexible way than vocalizations (e.g., Pollick & de Waal, 2007). Moreover, contrary to the claim that nonhuman primates only use gestures in dyadic contexts, namely to attract the attention of recipients to the self (Camaioni, 1997), several studies have shown that wild and captive individuals are also able to produce referential gestures to direct the attention of recipients towards external objects, events or locations (e.g., Leavens & Hopkins, 1998; Pika & Mitani, 2006; Veà & Sabater-Pi, 1998).

The use of pointing gestures by chimpanzees has been particularly investigated (e.g., Leavens & Hopkins, 1999). Although they mainly produce imperative gestures, a growing body of evidence suggests that chimpanzees, especially language-trained individuals, can use declarative pointing as well (e.g., Leavens, 2009). Thus, when they are reared in complex social and linguistic environments, nonhuman primates are capable of understanding (Lyn, Russell, & Hopkins, 2010) and producing declarative gestures to comment about objects and other individuals and make reference to both past and future events (Lyn, Greenfield, Savage-Rumbaugh, Gillespie-Lynch, & Hopkins, 2011). However, comparative studies have revelead some quantitative and qualitative differences between apes' and children's communicative skills (e.g., Greenfield & Savage-Rumbaugh, 1993; Pika, 2008). The production of spontaneous declarative gestures remains more frequent in children, and some declarative types, such as comments on another's possession of something, are rarely used by apes (Lyn et al., 2011). More generally, although the influence of environmental factors on the emergence of declarative communication needs further investigation (see Leavens & Bard, 2011), the complexity and versatility of children's pointing gestures have been argued to have no equivalent in nonhuman species (e.g., Kita, 2003; Tomasello et al., 2007). The social and cognitive abilities associated with communicative gestures, which seem to be manifest in early stages of infant's development, have also been regarded as a fundamentally human trait (e.g. Carpenter et al., 1998; Grosse, Behne, Carpenter, & Tomasello, 2010). The emergence of the ability to attribute mental states to others in a variety of contexts would therefore represent a milestone in the evolution of human behavior and cognition (e.g., Liszkowski et al., 2009). In particular, the production of informative gestures has been suggested to play an important role in the emergence of cooperation abilities, thus contributing significantly to the evolution of language (e.g., Bullinger, Zimmermann, Kaminski, & Tomasello, 2011).

Shedding some light on the processes involved in hemispheric specialization at the phylogenetic level, the study of hand-preference patterns in nonhuman primates has further supported the role of gestures in the shaping of human communication. Apes' communicative gestures are associated with a stronger degree of right-sided asymmetry than non-communicative manual actions, and individual hand preferences for these two different activities are not correlated with each other (e.g., Meguerditchian & Vauclair, 2009; Meguerditchian et al., 2010). In line with the hypotheses raised regarding human infant development, these results indicate first, that cerebral lateralization for communicative gestures and manipulative activities emerged through distinct processes in the course of evolution, and second that the left-hemisphere specialization in the last common ancestor of humans and great apes may have involved primarily the processing of communicative gestures. Moreover, the degree of population-level right-hand preference appears to be much stronger in humans than in nonhuman primates (see article VI), suggesting a relationship between the emergence of uniquely human social and cognitive abilities (see above) and increasing level of hemispheric specialization. The particularly strong degree of hand preference recorded in toddlers for informative gestures is congruent with this interpretation (see article III). Using event-related potentials in 20-month-old infants, Mills et al. (1993) have also demonstrated that increasing levels of language abilities were associated with increasing cerebral specialization of parietal and temporal regions in the left hemisphere.

In brief, studies conducted on human children and nonhuman primates have confirmed the primacy of gestures in language acquisition as well as the existence of a modality-independent communication system in the left cerebral hemisphere. However, we still have to trace the evolutionary scenario that led to the emergence of speech after humans' divergence from great apes some 6 million years ago. Gentilucci and Corballis (2006) have argued in favor of a progressive incorporation of the vocal modality into linguistic functions, but it is still unclear whether the left-hemisphere specialization for communicative behaviors initially involved gestures on their own, or else a combination of gestural and vocal signals. Recent evidence in nonhuman primates has supported a bimodal hypothesis of language origins (Hopkins, Taglialatela, & Leavens, 2011). Captive chimpanzees have been reported to produce intentionally atypical sounds – the “extended grunt” and the “raspberry”– to attract the experimenter’s attention in order to obtain some food (Hopkins, Taglialatela, & Leavens, 2007). Therefore, under some circumstances, great apes seem to be able to develop a voluntary control of their vocalizations. In addition, Hopkins and Cantero (2003) observed an increase in chimpanzees’ right-hand preference for communicative gestures when these gestures were produced simultaneously with vocal signals, compared to "silent gestures", thus reflecting a greater activation of the bimodal communication system in the left cerebral hemisphere.

The bimodal hypothesis of language origins is also supported by an experiment in human adults demonstrating bidirectional interactions between speech and gesture production systems. When the meaning of words and gestures simultaneously produced were congruent, participants' pointing gestures were performed faster and some frequencies of their voice spectra were found to be higher compared to the incongruent condition (Chieffi, Secchi, & Gentilucci, 2009). In infants, the early signs of lateralization for speech processing reported in neuroimaging studies (e.g., Dehaene-Lambertz, Hertz-Pannier, Dubois, & Dehaene, 2008) are consistent with a significant role of vocal signals in the development of cerebral specialization. Furthermore, the onset of babbling at around 7 months of age may contribute to the emergence of a speech–gesture system, with the two modalities mutually driving each other forward (Iverson, Hall, Nicke, & Wozniak, 2007). A study revealed an increase in repetitive right-handed activity in infants who had recently begun to babble, which might reflect the maturation of cerebral control mechanisms in the left-lateralized communication system (Locke, Bekken, McMinn-Larson, & Wein, 1995). Interestingly, infants born to deaf parents using sign language have been reported to babble silently with the hands (Petitto, Holowka, Sergio, & Ostry, 2003). Their rhythmic hand activity, different from the activity of speech-exposed infants, corresponded to the rhythmic pattern produced by adult signers, which highlights the importance of early language experience on the development of communicative behaviors, regardless of the modality. There is also evidence in deaf children that early and intensive exposure to sign language leads to a stronger left-hemisphere specialization for language processing than a later and less intensive exposure (Leybaert & D'Hondt, 2003).

To sum up, although the emergence of intentional and referential communication seems to involve the gestural modality at both the ontogenetic and phylogenetic levels, recent investigations have suggested that the evolutionary precursors of human language involve a combination of gestures and vocalizations (e.g., Masataka, 2008). This hypothesis obviously does not exclude the possibility of a gradual evolution of vocal signals in the course of evolution, along with anatomical specialization that makes speech possible (e.g., Lieberman, 2007). In this regard, Arbib (2005b) has proposed that protosign, namely a communication system based on manual and facial gestures, provided scaffolding for the emergence of protospeech, then leading to a gradual co-evolution of protosign and protospeech in an "expanding spiral". Moreover, the coupling between gestures and spoken language has been argued to involve a system of pantomimes (e.g., Gentilucci & Corballis, 2006), allowing the representation of both transitive and intransitive actions (i.e., actions associated or not with the use of objects, respectively). This hypothesis is consistent with results of a study conducted on epileptic individuals who were asked to pantomime the use of pictured tools (e.g., a key or a screwdriver) as they underwent an inactivation procedure of the left or right cerebral hemisphere (Meador et al., 1999). Language dominance was found to be more closely associated with hand preference for pantomimes – or in the authors' words "ideomotor praxis" – than with handedness assessed via a self-reported questionnaire. This study, illustrating further the existence of a bimodal communication system, supports Kendon's claim (2009) that pantomimes are equivalent to "communicative actions". Thus, the representation of actions through manual and facial gestures seems to be closely tied to communicative purposes. It has been suggested that the combination of pantomimes and vocalizations gradually evolved towards more symbolic forms of communication with the evolution of Hominin lineage, resulting eventually in the predominance of speech (e.g., Corballis, 2010).

7.1.4. Relation between language and gestures: neuroimaging literature

Neurobiological data in both human and nonhuman primates offer insight into the mechanisms that underlie the relationship between language and gestures, which allows us to confirm and complement findings from behavioral studies. The existence of a single system in charge of gestural and verbal communication has been supported by several brain imaging studies in human adults (e.g., Dick et al., 2009; Özyürek et al., 2007; Willems et al., 2007; Xu et al., 2009). This left-lateralized system appears to involve cerebral networks in inferior frontal regions including Broca's area (Gentilucci & Dalla Volta, 2007). Focusing on pointing gestures, Loevenbruck, Vilain and Dohen (2008) have suggested that a common cerebral network controls both gestural and vocal pointing, the latter referring to a deictic presentation form using syntactic or prosodic means. In addition, the production of syntactic pointing was shown to elicit cerebral activation in the left inferior frontal gyrus (Loevenbruck, Baciu, Segebarth, & Abry, 2005). Few studies are available regarding the neurological correlates of gesture production in children, but an event-related potential study showed that the perception of pointing gestures by 8-month-old infants elicits patterns of cerebral activation in posterior temporal regions similar to those recorded in adults (Gredebäck, Melinder, & Daum, 2010).

The present work has emphasized a clear distinction between manipulative activities and communicative gestures, but this question has never been investigated from a neurobiological perspective in children. Results from studies conducted on adults have revealed that complex processes underlied the relationship between action, gesture and language in the brain, with the idea that language is strongly rooted in mechanisms that evolved for interactions with the environment, namely in bodily action (e.g., Willems & Hagoort, 2007). A recent study using functional magnetic resonance imaging (fMRI) may shed some light on this issue. Right-handed participants were asked to plan familiar gestures in response to words referring to transitive or intransitive actions (e.g., cutting and scolding, respectively). Transitive and intransitive actions were found to be represented in a common left-lateralized network (Króliczak & Frey, 2009). The authors interpreted these findings as refuting the hypothesis that object-directed actions and intransitive gestures involve independent mechanisms within the left cerebral hemisphere. However, this interpretation is questionable because the participants were not asked to directly manipulate any objects. The production of both transitive and intransitive pantomimes relies on the representation of meaningful actions, which may be closely associated with communicative intentions. A similar design used with left-handed individuals has demonstrated, first, left-hemisphere dominance for language in the majority of the participants, confirming results of the study by Knecht et al. (2000). Second, individuals with bilateral or right-hemisphere dominance for language were found to exhibit similar atypical patterns of cerebral activation in inferior parietal regions (i.e., Brodmann area 40) when representing transitive or intransitive actions with either hand (Króliczak et al., 2011). Furthermore, the comparison of cerebral activations associated with actual execution of tool-use actions and pantomiming the same actions revealed a pantomime-specific left-lateralized activation in the superior/middle temporal gyrus (Lausberg et al., 2010). Therefore, these results support the hypothesis that gestural and verbal signals share a common cerebral specialization and highlight again the role of pantomimes in the evolution of representation and symbolic skills (see section 7.1.3.).

Moreover, the relationship between actions and communicative behaviors may be underlied by the mirror neuron system (MNS), which allows individuals to understand the actions performed by others through the activation of their own motor representations (e.g., Kilner, Friston, & Frith, 2007; Lamm, Fischer, & Decety, 2007). This understanding creates a link between individuals, who thus become potential communicative partners, and opens the door to the development of communicative skills. Involved in both the perception and the execution of hand and mouth actions, gestures and oro-facial communication, the MNS may therefore constitute an ideal substrate for the emergence of language (e.g., Rizzolati & Arbib, 1998). Recent evidence, although still limited, has suggested the presence of a MNS in infancy matching the perception and the execution of actions (see Lepage & Théoret, 2007 for a review). The MNS, along with the acquisition of motor skills allowing infants to interact with their environment in more and more various and complex ways (Iverson, 2010), may provide the necessary basis for the development of communication and language.

Thus, it can be hypothesized that actions, by virtue of the representational properties of the MNS, convey a communicative potential which is expressed during ontogenetic development through learning and experience, as infants and children act on their environment. Consistent with this hypothesis, experience has been shown to modulate the MNS responses in adults (e.g., Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005). Because mirror neurons are present in area F5 of the monkey's brain, which is regarded as the homologous of Broca's area (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), it has been suggested that similar mechanisms were involved in the course of human evolution (e.g., Corballis, 2010).

It should also be noted that this interpretation of the relationship between the control of action, gesture and language in the brain is not incompatible with the hypotheses raised in the present dissertation. Gestural and verbal communicative behaviors, initially grounded in mechanisms of perception, execution and representation of actions, may subsequently develop together with the specialization of a bimodal communication system in the left cerebral hemisphere, distinct from the one controlling purely motor functions of manipulation.

The investigation of the relationship between handedness for tool use and neuroanatomical asymmetries in nonhuman primates has provided further support to this hypothesis. In chimpanzees, researchers failed to find any significant association between handedness for reaching actions and structural asymmetries of two brain regions considered homologues to Broca's and Wernicke's areas (i.e., the fronto-orbital sulcus and the planum temporale). Significant correlations were found between asymmetry quotients and handedness for more complex manipulative actions such as termite fishing, but the percentage of variance explained hardly reached 15 % (Hopkins, Russell, & Cantalupo, 2007). By contrast, the right-sided bias recorded in chimpanzess for communicative gestures was reported to be associated with leftward structural asymmetries in the inferior frontal gyrus (Taglialatela et al., 2006). Hemispheric lateralization for communication processes is therefore more closely related to hand preference for gestures than for manual actions serving non-communicative purposes, which supports the prominent role of communicative gestures in the evolution of language and its hemispheric specialization.

7.2. Methodological issues

The present work has emphasized the relevance of focusing on manual asymmetries in both communicative and non-communicative behaviors to investigate speech–gestures links, but it has also raised some methodological challenges, notably pertaining to the study of language development and hand preference, which need to be addressed in future studies.

7.2.1. General issues

First, as brain activity is driven by multiple and complex mechanisms, seeking to unravel the cerebral processes involved in the development of communication by using behavioral measures may appear quite challenging. For example, even though neuroimaging studies have shown that the vast majority (around 90%) of adults present left-hemisphere dominance for language, it was not possible in the present work to determine with certainty which cerebral hemisphere controlled language functions for each participant. This question is even more problematic in children since the development of hemispheric specialization does not seem to be a linear process, as revealed by variations in the degree of hand preference during infancy (see article IV). If measures of structural and functional asymmetries via imaging techniques provide direct evidence of hemispheric lateralization, a more practical approach that could have been helpful for the purposes of this dissertation consists in using dichotic listening and divided visual field tasks. Such methods can even be used in neonates (e.g., Bertoncini et al., 1989) and although based on behavioral measures, they will enable us in future studies to assess hemispheric asymmetries and differentiate participants with left-hemisphere dominance from participants showing right-hemisphere dominance or bilateral control for language.

Second, the difference between experimentally induced and spontaneous pointing gestures deserves further investigation. Pointing gestures produced in a naturalistic context (article II) were associated with a stronger right-sided bias and were more frequently accompanied by vocalizations than gestures elicited in experimental contexts (articles III–V). These differences may be a consequence of the relatively small sample size and of the absence of left-handed children for pointing gestures in the naturalistic study (article II), but they may also reflect the influence of some features characterizing each setting. Although both spontaneous and induced pointing involved a communicative intention, experimental contexts may to some extent restrain toddlers' natural communicative behaviors, notably their vocalizations, which might also affect manual asymmetries. However, this possibility is reduced given that the methods, materials and setting (home and day-care centers) of the experimental studies were chosen on the strength of their ecological validity.

Moreover, examining the spontaneous production of gestures is a fruitful approach for studying the development of communicative behaviors, but several variables cannot be directly controlled. In the observational study presented in this dissertation, special attention was paid to the position of the gesturer and to the position of the referent in the child's visual field, but the distance between the child and the pointed object or event was not taken into account. However, this distance may influence some features of children's gestures and vocalizations. Distal pointing gestures were found to be associated with longer durations and higher voice frequencies (F1) of accompanying vocalizations than proximal pointing gestures (Gonseth, Vilain, & Vilain, 2010).

7.2.2. Language

In the present work, language level was assessed through direct observation of children's abilities in different tasks and through parental reports. Although they provided a reliable measure of children's linguistic skills, these language tests focused only on lexical production (articles III and V) or yielded a raw score that did not allow us to distinguish between production and comprehension of language, nor between lexical and syntactic skills (article IV). A thorough investigation of these different language components is needed to examine further speech–gesture links because they may be associated with distinct processes and relate to gestural communication to various extents. For example, 18-month-old children's gestural vocabulary (defined as the number of different meanings expressed through gestures) was shown to be correlated to the verbal vocabulary size at 42 months of age, whereas speech–gesture combinations produced at 18 months of age (in which gesture and speech convey two different ideas) were a strong predictor of later two-word combinations (Rowe & Goldin-Meadow, 2009).

Moreover, significant results regarding the relationship between hand preference and language level referred to the lexical spurt period, whose onset was assumed to be associated with the 50-word stage (article V). However, some studies, although involving few participants, have shown that a number of children begin to experience a lexical spurt at a productive vocabulary size of more than 50 words (e.g., Mervis & Bertrand, 1995). It has also been argued that some children never evidence a lexical spurt (e.g., Bloom, 2001; Ganger & Brent, 2004; Goldfield & Reznick, 1990). Therefore, even if the lexicon size has been regarded as a more reliable indicator of the vocabulary spurt than age (e.g., Nazzi & Bertoncini, 2003), the 50-word threshold does not take into account interindividual variability (see also Parladé & Iverson, 2011). Additional measures may thus be needed to determine precisely the onset and the duration of the lexical spurt for each child. In addition, the use of parental reports to assess children's language level, such as the MacArthur Communicative Development Inventories has been criticized for lack of validity and accuracy (e.g., Feldman et al., 2000). Although several studies have reported significant correlations between parental reports and direct measures of language abilities (e.g., Dyer Ring & Fenson, 2000; Fenson et al., 2000; Heilmann, Weismer, Evans, & Hollar, 2005), it may be more cautious to combine both sources of information.

The study of the vocalizations produced along with children's gestures also deserves a more precise analysis to distinguish between the production of sentences, words and other vocal sounds. Moreover, spectrographic analysis would enable us to characterize vocalizations in terms of amplitude, frequency and rhythm, which may provide additional information as to the difference between imperative and declarative communication. The kinematics of pointing gestures in relation to speech and vocalizations needs to be further investigated as well. We considered that vocalizations and pointing gestures were coincident in time when they were produced at the precise moment of the pointing gesture (article III) or within a two-second interval (article II). This discrepancy may account for the different proportions of "vocal gestures" recorded in these studies (see also section 7.2.1.). More generally, it would be useful to examine precisely kinematic and temporal features of pointing gestures, as the latter are likely to vary across individuals and as a function of the communicative context. This may also help determine the different intentions associated with pointing, as children usually prolong their gestures until they reach their communicative goals. In the study with adults (article VI), examining pointing kinematics may also have offered further information related to the influence of speech on hand preference for gestures. Pointing and speech were produced simultaneously, but the duration of pointing gestures probably differed between participants, which should be measured in future studies.

7.2.3. Hand preference

Contrary to studies involving human adults or captive nonhuman primates, children's hand preference are assessed from a limited number of trials, varying approximately between 2 and 10 responses across studies (e.g., Fagard & Marks, 2000; Vauclair & Imbault, 2009, and see articles II–V of the present dissertation). Increasing the number of trials is not always possible as it can be difficult to elicit communicative gestures and maintain children's attention over long periods of time. However, this does not mean that hand-preference patterns are not reliably assessed, although it may be important for comparison purposes to measure hand preference in different manual activities (e.g., pointing gestures and grasping actions) using a similar number of responses. Another precaution consists in calculating handedness indexes, which indicate both the strength and the direction of hand preferences, thus providing a more complete measure of manual asymmetries than the categorization as left-hander or right-hander. Moreover, researchers use different criteria to categorize participants, whereas handedness scores enable an easier comparison between studies.

Another issue related to the study of manual asymmetries concerns the variety of assessments methods, in relation with the researchers' definition of handedness. Beyond the distinction between manipulative activities and communicative gestures whose necessity has been demonstrated in the present work, it is important to differentiate hand-performance measures from hand-preference measures (e.g., Brown et al., 2004), as well as unimanual tasks from bimanual manipulative tasks (e.g., Fagard & Lockman, 2005). Ideally, several measures of handedness should be used to get a complete picture of functional asymmetries. Even when this is not possible, the multiple dimensions of handedness should be kept in mind and the choice to focus on one specific dimension should be justified on theoretical grounds (e.g., Healey et al., 1986, and see Chapter 3).

7.2.4. Hand shapes

Another point deserving further investigation is the study of hand shapes, especially as it was used as an indicator of different origins of gestures. In the present work, gestures were coded as index-finger pointing when the index finger was extended and the other fingers tightly or more lightly curled and as whole-hand pointing when all the fingers were extended. A more accurate categorization, based on quantitative measures, is needed to identify more precisely the relationship between hand shapes and the functions of the gestures. Studies are currently in process to quantitatively analyze hand shapes associated with pointing gestures, by means of a software developed in our laboratory (*Video Analyser*). This software provides measures of distances and angles as a function of markers that we place on the images extracted from videos. For example, measures of the angle between the extremity of the index finger, the base of the index and middle fingers, and the extremity of the middle finger allow us to differentiate precisely index-finger gestures from whole-hand gestures and to describe intermediate hand shapes that could reflect a shift in the nature of children's communicative skills (see section 7.1.1.).

Furthermore, some factors other than communicative functions may influence hand shapes, such as the degree of precision required for the recipient to identify the referent pointed at. In adults, index-finger pointing is frequently used to disambiguate referential situations whereas whole-hand pointing and thumb pointing are mostly produced in situations requiring little precision (e.g., Kendon & Versante, 2003). Although children's and adults' gestural communication differs in many ways, it can be hypothesized, for example, that children are more likely to use index-finger pointing to request an object that is surrounded by several other objects than to request an isolated object. Such an influence of environmental conditions on hand shapes has been reported in two signing chimpanzees (Krause & Fouts, 1997). Moreover, the distance between the gesturer and the referent may be associated with the level of precision required to indicate a specific object, event or location to a recipient, distal pointing being in essence less accurate than proximal pointing. Therefore, the influence of this distance on hand shapes also needs to be taken into account in future studies.

7.3. Future directions of research

The studies presented in this dissertation have provided valuable insights into the relationship between language development and communicative gestures, but some questions still need to be answered. In this section, I describe the main directions that would be worth considering in future studies in order to deepen our understanding of speech gesture–links, in relation to the processes of hemispheric specialization.

7.3.1. Hand preference in late childhood

Researchers have studied hand preference for symbolic gestures and pointing in infants (e.g., Bates et al., 1986; Young et al., 1985) and for co-speech gestures in adults (e.g., Kimura, 1973), but there are no data available on hand preference for communicative gestures in childhood. The development of hand preference therefore needs to be investigated from the production of the first intentional communicative gestures – at around 1 year of age – to approximately 10 years of age to determine whether, as we have hypothesized (see section 7.1.1.), the right-sided asymmetry for gestures is already strongly established in early stages and only slightly increases after the third year of life. It would also be interesting to examine the relationship between the development of hand preference and changes in the use of communicative gestures as children grow up. The degree of right-sided asymmetry may stabilize when gestures are no longer used as the main communicative modality, but rather as props for speech.

Regarding handedness for manipulative activities, there is some evidence showing that the right-sided bias becomes stable at approximately 7 years of age (McManus et al., 1988). This result needs to be replicated though, using several assessment methods – the study by McManus et al. (1988) focused only on unimanual activities. It would also be valuable to study the relationship between the increase in the degree of handedness and the frequency and complexity of object manipulations performed by children.

Moreover, hand preference for communicative gestures and handedness for manipulative actions were found to be more closely associated in adults than in toddlers (see article VI). Investigating manual asymmetries in late childhood would allow us to determine whether the interrelations between communicative and non-communicative activities emerge gradually in the course of development or else by stages, as children acquire specific motor and/or linguistic skills.

7.3.2. Different communicative gestures?

The present work has focused on pointing gestures, but infants and children use a variety of other communicative gestures, which may present different developmental trajectories and different relationships with language acquisition. The characteristics of these gestures should therefore be investigated throughout development, starting with representational gestures. Because they directly convey a specific meaning through the representation of an object or an action, iconic and symbolic gestures may indeed play a role in language development (e.g., Goodwyn et al., 2000), although pointing has been regarded as "the royal road to language" (Butterworth, 2003). Complex dynamic relationships have been reported between pointing and symbolic gestures produced by young children between 6 and 18 months of age (Vallotton, 2010). Infants' early pointing behavior was shown to predict development of a greater variety of symbolic gestures, while the use of symbolic gestures at later stages reduced the frequency of pointing. Moreover, the use of both symbolic gestures and pointing were found to decrease as speech develops, but pointing remained a communication tool integrated into multimodal language. Thus, symbolic gestures have been argued to take on the role of words for preverbal children, which may also support the importance of pantomimes in the evolution of language (e.g., Gentilucci, Dalla Volta, & Gianelli, 2006; Kendon, 2009). This hypothesis is consistent with recent evidence reporting the production of meaningful communicative gestures in nonhuman primates, which might reflect the precursors of representational abilities characterizing human species (e.g., Laidre, 2011).

In addition, the comparison of hand preferences for deictic and symbolic gestures would shed some light on the development of left-hemisphere specialization for communicative behaviors. In the study by Bates et al. (1986), both pointing and symbolic gestures were found to be more right-handed than non-communicative manual actions, but pointing gestures were associated with a stronger right-sided asymmetry than symbolic gestures. However, in that study, the production of gestures in the symbolic play task was based on imitation of the experimenter, and even if these symbolic gestures were used during interactions with adults, they may not involve children's genuine communicative intention. Therefore, there is still much to explore regarding the relationship between pointing and symbolic gestures and their respective roles in language acquisition and hemispheric specialization.

Moreover, research on gestural communication has mainly focused on empty-handed gestures, but the production of object-directed communicative gestures also deserves an examination. Investigations of gestures such as “give” and “show” might improve our understanding of the relationship between the control of communicative gestures and manipulative activities.

Lastly, the production of speech-accompanying gestures, which has been widely studied in adults, needs to be examined in the course of development. Although we are generally not aware of producing or perceiving them, co-speech gestures produced by adults are omnipresent and play a crucial role in face-to-face communication for both speaker and listener (e.g., Kendon, 2004; McNeill, 1992). Moreover, the asymmetry of some co-speech gestures appears to be influenced by the nature of speech content (Kita et al., 2007). For these reasons, co-speech gestures provide helpful insights into the functioning of the left-lateralized bimodal communication system. As children grow older and use verbal language in more complex ways, co-speech gestures have been reported to develop from mainly representational gestures to more complex forms of gesticulation (Coletta, Pellenq, & Guidetti, 2010). It would be relevant to investigate further the relationship between co-speech gestures and the development of linguistic skills and to examine whether the change in the production of these gestures is associated with a change in hand-preference patterns.

7.3.3. Role of cooperation abilities in language acquisition

The study of hand preference in different pointing contexts has revealed a particularly strong right-sided bias for declarative informative gestures (article III), which poses a challenge of great theoretical significance for understanding human communication development. Informative pointing is used to provide recipients with information they need about a referent and may therefore be associated with the development of cooperation abilities (Liszkowski et al., 2008). Studies have demonstrated that peer cooperation develops over the second and third years of life, in association with advances in social understanding (e.g., Brownell, Ramani, & Zerwas, 2006). This is consistent with our results: although informative gestures were scarcely produced spontaneously by toddlers (article II), the ability to use informative pointing in experimental conditions was found to increase between 15 and 30 months of age (article III). Moreover, our results have shown that gaze alternation between the adult and the object being pointed to accompanies informative gestures more frequently than gestures serving other communicative functions. Thus, children are more likely to monitor their partner's activity in informative contexts, which supports the relationship between the production of cooperative gestures and the development of early social understanding – namely the ability to represent the mental states that motivate others' actions (see also Liszkowski et al., 2006).

Because they are closely related to the development of social skills and associated with a strong degree of right-hand preference, children's informative gestures may play a privileged role in language acquisition and in left-hemisphere specialization. However, additional studies are necessary to confirm the existence of specific hand-preference patterns for gestures produced in a cooperative context. Moreover, there are different kinds of cooperative behaviors, involving different levels of complexity (Svetlova, Nichols, & Brownell, 2010). For example, instrumental cooperation is based on the understanding of another person's goal, whereas emphatic cooperation requires the understanding of another person's mental state. In the first case, children intend to facilitate an interrupted goal-directed action, while in the second case, which corresponds to the informative situation of our study (article III), children seek to modify a communicative partner's state. Thus, future studies need to be conducted to investigate to what extent these different cooperative behaviors contribute to language acquisition, in relation to the development of manual asymmetries. It would also be useful to explore the spontaneous use of informative gestures during development to determine precisely when such gestures become part of children's natural repertoire.

Lastly, cooperative behaviors have been argued to play an important role in the evolution of language (e.g., Bullinger et al., 2011; Tomasello, 1999). Examining the production of informative gestures in nonhuman primates, including the patterns of hand preference associated with these gestures, may therefore improve our understanding of the relationship between cooperative gestures and language acquisition at the phylogenetic level.

To conclude, although some methodological issues are still to be improved, the present work has provided significant data regarding the relationship between communicative gestures and language development by examining different functions of pointing gestures. In addition, the study of hand preference has offered some insights into the complex mechanisms of cerebral specialization for communicative behaviors. Integrated into a phylogenetic approach, our results may also contribute to improve current understanding of the evolutionary roots of human language. Lastly, the suggested directions for future research will probably yield some answers to the remaining questions around the fascinating and remarkably rich subject of gestural communication.

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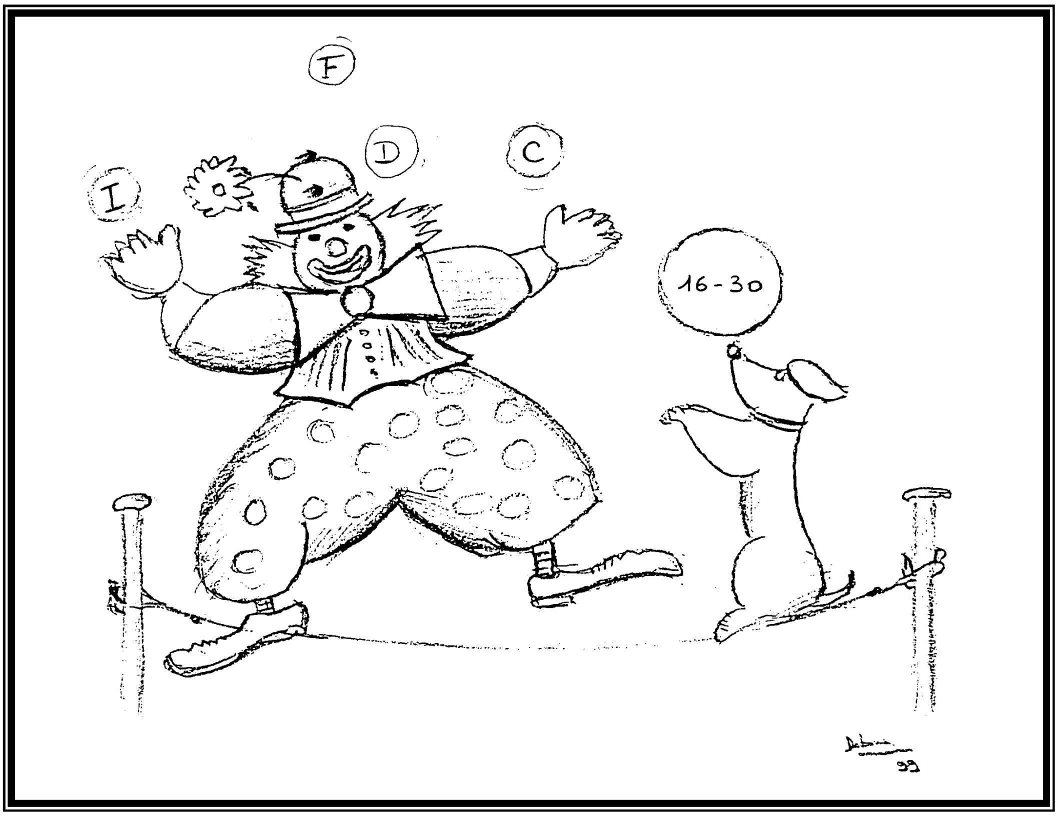
Appendices

- **Appendix 1.** Language level assessment: Parental questionnaire based on the French adaptation (Kern, 2003) of the MacArthur Communicative Development Inventories (Fenson et al., 1993).

- **Appendix 2.** Items of the *language* sub-test of the French Brunet-Lézine scale (1965), revised by Josse (1997).

Inventaire Français
du Développement Communicatif
chez le nourrisson : mots et phrases

Institut des Sciences de l'Homme. 14, avenue Berthelot, 69363 Lyon cedex 07. France



Vous avez accepté de participer à ce projet. Nous vous en remercions.

SUJET	☐☐☐☐

AGE	☐☐

Nom de la personne "contact" (pédiatre, chercheur) : ____________________

INFORMATIONS SUR L'ENFANT

Prénom ____________________

Sexe ____________________

Date de naissance ____________________

Age (en nombre de mois) ____________________

L'enfant fréquente-t-il ou a-t-il fréquenté la crèche ? ____________________

L'enfant fréquente-t-il l'école ? ____________________

INFORMATIONS SUR LA FAMILLE

Nombre de frères et sœurs ____________________ Ages ____________________

Lieu de résidence ____________________

Age : mère ____________________ père ____________________

Dernier diplôme obtenu : mère ____________________ père ____________________

Profession : mère ____________________ père ____________________

Langues parlées à la maison ? ____________________

DESCRIPTION DE SON APPROCHE AU LANGAGE

		oui	non
A	Bavard	☐	☐
B	Répétitions d'une même syllabe (dada)	☐	☐
C	Répétitions de syllabes différentes (bodi)	☐	☐
D	Imitations de l'intonation adulte	☐	☐
E	Aime la musique	☐	☐
F	Demande les noms des objets	☐	☐

DESCRIPTION DE SON DEVELOPPEMENT PSYCHOMOTEUR

Marche ?

seul ____________________ Si oui, depuis quel âge ? ____________________

avec aide ____________________ Si oui, depuis quel âge ? ____________________

VOCABULAIRE

Regardez SVP la liste suivante et cochez les mots que <u>votre enfant utilise en ce moment</u>.

Cris d'animaux et sons

1	bêê bêê	☐
2	tchou tchou	☐
3	cocorico	☐
4	grrrr	☐
5	miaou	☐
6	meuh	☐
7	allô	☐
8	aïe	☐
9	coin-coin	☐
10	oh oh	☐
11	vroum	☐
12	ouaf-ouaf	☐
13	miam-miam	☐

Véhicules (vrais ou jouets)

14	avion	☐
15	vélo	☐
16	bus	☐
17	voiture	☐
18	camion de pompier	☐
19	moto	☐
20	poussette	☐
21	train	☐
22	camion	☐
23	bateau	☐
24	hélicoptère	☐
25	traîneau	☐
26	tracteur	☐
27	tricycle	☐

Jouets

28	balle	☐
29	ballon	☐
30	cube	☐
31	livre	☐
32	bulles	☐
33	poupée	☐
34	crayon	☐
35	feutre	☐
36	stylo	☐
37	jouet	☐
38	raquette	☐
39	craie	☐
40	jeu	☐
41	colle	☐
42	pâte à modeler	☐
43	cadeau	☐
44	puzzle	☐
45	histoire	☐

Noms d'animaux (vrais ou jouets)

46	animal	☐
47	ours	☐
48	abeille	☐
49	oiseau	☐
50	petite bête	☐
51	lapin	☐
52	papillon	☐
53	chat	☐
54	poule	☐
55	vache	☐
56	biche	☐
57	chien	☐
58	âne	☐
59	canard	☐
60	éléphant	☐
61	poisson	☐
62	grenouille	☐
63	girafe	☐
64	chèvre	☐
65	oie	☐
66	cheval	☐
67	bébé chat	☐
68	agneau	☐
69	lion	☐
70	singe	☐
71	souris	☐
72	hibou	☐
73	pingouin	☐
74	cochon	☐
75	poney	☐
76	bébé chien	☐
77	mouton	☐
78	écureuil	☐
79	nounours	☐
80	tigre	☐
81	dindon	☐
82	tortue	☐
83	crocodile	☐
84	fourmi	☐
85	zèbre	☐
86	renne	☐
87	coq	☐
88	loup	☐

Nourriture et boisson

89	lait	☐
90	céréales	☐
91	cornflakes	☐
92	orange	☐
93	fromage	☐
94	petits pots	☐
95	poulet	☐
96	pizza	☐
97	café	☐
98	raisin	☐
99	petits gâteaux	☐
100	spaghetti	☐
101	gâteaux apéro	☐
102	tartine	☐
103	pomme	☐
104	œuf	☐
105	banane	☐
106	poisson	☐
107	pain	☐
108	nourriture	☐
109	beurre	☐
110	glace	☐
111	gâteau	☐
112	jus de fruit	☐
113	sucre	☐
114	viande	☐
115	carotte	☐
116	boisson	☐
117	eau	☐
118	clémentine	☐
119	purée	☐
120	petits pois	☐
121	baguette	☐
122	soupe	☐
123	pâtes	☐
124	thon	☐
125	kiwi	☐
126	compote	☐
127	haricot	☐
128	chocolat	☐
129	coca	☐
130	maïs	☐
131	beignet	☐
132	frites	☐
133	haricots verts	☐
134	chewing-gum	☐
135	hamburger	☐
136	glaçon	☐
137	vitamines	☐
138	bonbons	☐
139	confiture	☐
140	yaourt	☐
141	sucette	☐
142	melon	☐
143	madeleine	☐
144	noisettes	☐
145	crêpe	☐
146	nutella	☐
147	mayonnaise	☐
148	pop-corn	☐
149	esquimau	☐
150	pomme de terre	☐
151	chips	☐
152	bretzel	☐
153	flan	☐
154	courge	☐
155	raisins secs	☐
156	sel	☐
157	sandwich	☐
158	sauce	☐
159	limonade	☐
160	fraise	☐
161	vanille	☐

Vêtements

162	perles	☐
163	collier	☐
164	bavoir/bavette	☐
165	pyjama	☐
166	bottes	☐
167	pantalon	☐
168	boutons	☐
169	chemise	☐
170	manteau	☐
171	chaussure	☐
172	couche	☐
173	body	☐
174	grenouillère	☐
175	short	☐
176	robe	☐
177	chaussettes	☐
178	chapeau	☐
179	sweet	☐
180	veste	☐
181	tee-shirt	☐
182	jeans	☐
183	salopette	☐
184	chausson/pantoufle	☐
185	pull	☐
186	ceinture	☐
187	gants	☐
188	moufles	☐
189	écharpe	☐
190	basket	☐
191	combinaison de ski	☐
192	collants	☐
193	culotte/slip	☐

Parties du corps

194	bras	☐
195	nombril	☐
196	joue	☐
197	oreille	☐
198	yeux	☐
199	figure/visage	☐
200	pied	☐
201	doigt	☐
202	cheveux	☐
203	main	☐
204	tête	☐
205	genou	☐
206	jambe	☐
207	bouche	☐
208	nez	☐
209	aïe bobo	☐
210	dent	☐
211	doigt de pied	☐
212	langue	☐
213	ventre	☐
214	cheville	☐
215	fesses	☐
216	menton	☐
217	lèvre	☐
218	pénis/zizi…	☐
219	cœur	☐
220	vagin/zezette…	☐
221	pouce	☐

Meubles et pièces

222	salle de bain	☐
223	baignoire	☐
224	lit	☐
225	chambre	☐
226	chaise	☐
227	canapé	☐
228	berceau	☐
229	porte	☐
230	tiroir	☐
231	garage	☐
232	chaise haute	☐
233	cuisine	☐
234	salon	☐
235	four	☐
236	parc	☐
237	pot	☐
238	frigo	☐
239	fauteuil	☐
240	lavabo	☐
241	escalier	☐
242	cuisinière	☐
243	table	☐
244	télé	☐
245	fenêtre	☐
246	étendage	☐
247	entrée	☐
248	douche	☐
249	pièce	☐
250	cave	☐
251	banc	☐
252	wc	☐
253	machine à laver	☐
254	évier	☐

Jeux et routines

255	bain	☐
256	petit déjeuner	☐
257	au revoir	☐
258	dîner	☐
259	ne fais pas	☐
260	bonjour	☐
261	salut	☐
262	déjeuner	☐
263	sieste	☐
264	bonne nuit	☐
265	non	☐
266	ainsi font font	☐
267	coucou	☐
268	s'il te plaît	☐
269	chut	☐
270	merci	☐
271	oui	☐
272	bravo	☐
273	faire les courses	☐
274	goûter	☐
275	coup de fil	☐
276	top là	☐
277	je vais t'attraper	☐
278	va sur le pot	☐
279	tourne-toi	☐
280	ce petit cochon	☐

Endroits où aller

281	plage	☐
282	camping	☐
283	église	☐
284	cirque	☐
285	campagne	☐
286	centre-ville	☐
287	ferme	☐
288	station service	☐
289	maison	☐
290	cinéma	☐
291	dehors	☐
292	parc	☐
293	fête	☐
294	pique-nique	☐
295	terrain de jeux	☐
296	école	☐
297	magasin	☐
298	forêt	☐
299	travail	☐
300	cour	☐
301	zoo	☐
302	garderie	☐
303	crèche	☐

Prépositions et localisations

304	au sujet de	☐
305	au dessus de	☐
306	autour de	☐
307	à	☐
308	loin	☐
309	derrière	☐
310	à côté de	☐
311	chez	☐
312	en bas	☐
313	pour	☐
314	ici	☐
315	à l'intérieur de	☐
316	dans	☐
317	près de	☐
318	de	☐
319	au loin	☐
320	sur	☐
321	au sommet de	☐
322	dehors	☐
323	par dessus	☐
324	là-bas	☐
325	vers	☐
326	sous	☐
327	en haut	☐
328	avec	☐
329	là	☐

Interrogatifs

330 comment
331 quoi
332 quand
333 où
334 qui
335 pourquoi
336 le/la/les/quel(les)

Quantificateurs et articles

337 tous/tout
338 un autre
339 encore
340 aucun/ne
341 pas
342 le/la même
343 un peu
344 aucun/e
345 un/une
346 plein/beaucoup
347 du/de la/des
348 chaque
349 autre
350 le/la/les
351 aussi

Pronoms

352 à elle/sa
353 à lui/son
354 je
355 ça
356 moi
357 à moi
358 ma/mon/mes
359 vous/tu
360 votre/ta/ton
361 il
362 ses
363 lui
364 moi-même
365 notre
366 elle
367 leur
368 eux
369 ces
370 ils/elles
371 ceux
372 nous
373 on
374 toi-même

Mots sur le temps

375 jour
376 après
377 matin
378 nuit
379 maintenant
380 aujourd'hui
381 demain
382 ce soir
383 avant
384 heure
385 hier

Connecteurs

386 et
387 parce que
388 mais
389 si
390 donc
391 alors

Objets d'extérieurs

392 rocher
393 nuage
394 drapeau
395 fleur
396 jardin
397 herbe
398 lune
399 tuyau
400 échelle
401 tondeuse à gazon
402 piscine
403 pluie
404 caillou
405 toit
406 pelle
407 bac à sable
408 toboggan
409 neige
410 étoile
411 trottoir
412 soleil
413 balançoire
414 arbre
415 eau
416 ciel
417 bonhomme de neige
418 arrosoir
419 bâton
420 pierre
421 rue/route
422 vent

Personnes

423 tante
424 bébé
425 nounou
426 nom de la nounou
427 garçon
428 frère
429 enfant
430 papa
431 fille
432 grand-mère
433 grand-père
434 dame
435 maman
436 nom de l'enfant
437 gens
438 personne
439 sœur
440 maître/sse
441 oncle
442 monsieur
443 clown
444 docteur
445 pompier
446 copain/ine
447 facteur
448 infirmière
449 police
450 nom de l'animal domestique

Auxiliaires

451 suis
452 sont
453 être
454 est
455 peux
456 pourrait
457 a fait
458 faire
459 fait
460 ne pas
461 aller
462 devoir faire
463 avoir à faire
464 laisse-moi
465 avoir besoin de
466 essayer de
467 vouloir
468 était

Petits objets ménagers

469 couverture
470 bouteille
471 bol
472 boite
473 balai
474 brosse
475 horloge
476 peigne
477 tasse
478 plat
479 fourchette
480 verre
481 lunettes
482 marteau
483 clefs
484 lampe
485 lumière
486 médicaments
487 argent
488 papier
489 sous/pièces
490 photo
491 oreiller
492 plante
493 assiette
494 porte-monnaie
495 radio
496 ciseaux
497 savon
498 cuillère
499 téléphone
500 brosse à dent
501 serviette
502 poubelle
503 aspirateur
504 montre
505 feuille
506 musique
507 sirop
508 biberon
509 télécommande
510 sucette
511 panier
512 seau
513 appareil photo
514 ordures
515 pot
516 couteau
517 serpillière
518 clou
519 serviette de table
520 cassette
521 mouchoir
522 plateau
523 trotteur
524 coussins

Mots descriptifs

525 parti
526 endormi
527 pas bon
528 grand
529 bleu
530 cassé
531 attention
532 propre
533 froid
534 mignon/ne
535 sombre
536 sale
537 sec/che
538 vide
539 vite
540 bien
541 doux/ce
542 bon/ne
543 content/te
544 dur
545 chaud/e
546 avoir faim
547 blessé
548 petit/e
549 vilain/e
550 gentil/le
551 vieux/vieille
552 joli
553 rouge
554 avoir peur
555 malade
556 avoir sommeil
557 tendre
558 avoir soif
559 fatigué
560 mouillé
561 dégoûtant/e
562 beau/belle
563 méchant/e
564 être réveillé
565 mieux
566 noir
567 marron
568 premier/ère
569 plein/ne
570 vert/e
571 lourd/e
572 haut/e
573 dernier/e
574 long/ue
575 fort/e
576 fou/folle
577 neuf/ve
578 bruyant/e
579 orange
580 tranquille
581 triste
582 lent/e
583 coincé
584 collant/e
585 minuscule
586 blanc/he
587 venteux
588 jaune
589 coquin/e

Mots d'action

590 mordre
591 souffler
592 casser
593 apporter
594 se cogner
595 nettoyer
596 fermer
597 pleurer
598 danser
599 dessiner
600 boire
601 conduire
602 manger
603 tomber
604 nourrir
605 finir
606 recevoir
607 donner
608 aller
609 aider
610 taper
611 prendre dans ses bras
612 se dépêcher
613 sauter
614 donner un coup
615 faire un bisou
616 regarder
617 laver
618 aimer
619 ouvrir
620 jouer
621 tirer
622 pousser
623 mettre
624 lire
625 faire du vélo/moto
626 courir
627 dire
628 voir
629 montrer
630 chanter
631 dormir
632 sourire
633 éclabousser
634 arrêter
635 nager
636 balancer
637 prendre
638 jeter
639 chatouiller
640 toucher
641 marcher
642 essuyer
643 écrire
644 construire
645 acheter
646 porter
647 attraper
648 courir après
649 faire bravo
650 sécher
651 déposer
652 trouver
653 aller bien avec
654 réparer
655 détester
656 avoir
657 entendre
658 cacher
659 tenir
660 couper
661 frapper à la porte
662 lécher
663 aimer bien
664 écouter
665 faire
666 ramasser
667 faire de la peinture
668 renverser
669 verser
670 faire semblant
671 goutter
672 déchirer
673 secouer
674 partager
675 s'asseoir
676 faire du patin
677 glisser
678 travailler
679 souhaiter
680 être debout
681 rester
682 balayer
683 parler
684 goûter
685 arracher
686 penser
687 attendre
688 se réveiller
689 couvrir
690 grimper
691 cuisiner

MERCI POUR VOTRE PARTICIPATION

Items of the *language* sub-test of the French Brunet-Lézine scale (1965), revised by Josse (1997)

Nom :
Date de naissance :
Date de passation :

Prénom :
Age :
Session :

Mois	Points	Succès/Echec	Items
10	16		Dit un mot de 2 syllabes **(Q)**
12	18		Secoue la tête pour dire non **(Q)**
	20		Jargonne de manière expressive (longues suites sonores modulées comme une phrase) **(Q)**
14	22		Utilise des onomatopées qui font office de mots (vroum vroum, wouah wouah…) **(Q)**
	24		Identifie 1 objet (sur les 5 présentés)
17	27		Dit 5 mots **(Q)**
	30		Identifie 3 objets
20	33		Nomme 2 ou montre 4 images (planche 1)
	36		Identifie 4 objets (nommés ou donnés)
	39		Fait des phrases de 2 mots **(Q)**
24	43		Nomme 6 images (planches 1 & 2)
	47		Identifie 8 objets ou en nomme 4
	51		Fait des phrases de 3 mots **(Q)**
	55		Utilise son prénom quand il parle de lui-même ou d'un objet qui lui appartient **(Q)**
30	61		Nomme 10 images (planches 1 & 2)
	67		Nomme 8 objets ou plus
	73		Utilise 1 des pronoms "je, tu, il, elle" **(Q)**

Total de points :
Age de développement :
Quotient de développement :

Q : Questions posées aux parents si l'observation ne suffit pas.

Curriculum vitae

Hélène COCHET

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Research Center in the Psychology of Cognition, Language, and Emotion
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DEGREES

- **Ph.D. in Psychology** (University of Provence, France, 2011): "Hand shape, function and hand preference of communicative gestures in young children: Insights into the origins of human communication" under the supervision of Prof. Jacques Vauclair. Thesis defence scheduled on September 23, 2011.
- **M.A. in Psychology** (University of Provence, France, 2008), *summa cum laude*
- **B.A. in Biology** (University of Tours, France, 2006), *magna cum laude*

RESEARCH TOPICS

My research interests concern the relation between **gestural communication** and **language** development, mainly through the study of hand preferences, hand shapes and hand functions. Within a framework about the origins of language, I have conducted experimental and observational researches in human infants and adults, focusing on two main questions:

- Comparison of hand preferences for communicative gestures and object-directed activities in human infants and adults.
- Study of the different functions of **pointing** gestures produced by infants and toddlers (including hand preference, hand shapes, accompanying vocalizations, gaze alternation).

PUBLICATIONS

- **Cochet, H.** (2011). Development of hand preference for object-directed actions and pointing gestures: A longitudinal study between 15 and 25 months of age. *Developmental Psychobiology.* (in press).
- **Cochet, H.**, Jover, J., & Vauclair, J. (2011). Hand preference for pointing gestures and bimanual manipulation around the vocabulary spurt period. *Journal of Experimental Child Psychology* (in press). DOI. 10.1016/j.jecp.2011.04.009.
- **Cochet, H.**, & Vauclair, J. (2011). Hand preferences in human adults: Noncommunicative actions versus communicative gestures. *Cortex* (in press). DOI: 10.1016/j.cortex.2011.03.016.

- **Cochet, H**., & Vauclair, J. (2010). Pointing gesture in young children: Hand preference and language development. *Gesture, 10*(2/3), 129–149.
- **Cochet, H**., & Vauclair, J. (2010). Features of spontaneous pointing gestures in toddlers. *Gesture, 10*(1), 86–107.
- **Cochet, H**., & Vauclair, J. (2010). Pointing gestures produced by toddlers from 15 to 30 months: Different functions, hand shapes and laterality patterns. *Infant Behavior and Development*, *33*, 432–442.
- Meguerditchian, A., **Cochet, H**., & Vauclair, J. (2011). From gesture to language: ontogenetic and phylogenetic perspectives on gestural communication and its cerebral lateralization. In A. Vilain, J.L. Schwartz, C. Abry, & J. Vauclair (Eds.), *Primate Communication and Human Language: Vocalisation, gestures, imitation and deixis in humans and non-humans* (pp. 89–118). Amsterdam: John Benjamins.
- Vauclair, J., & **Cochet, H**. (in press). Speech-gesture links: A focus on the ontogeny and phylogeny of gestural communication and left-hemisphere specialization for language. In R. Botha, & M. Everaert (Eds.), *The Evolutionary Emergence of Language: Evidence and Inference (Studies in the Evolution of Language).* Oxford: Oxford University Press.

PRESENTATIONS

- **Cochet, H.**, & Vauclair, J. (2011, August). *Hand use for gestural communication in the course of speech development.* Oral presentation at the 15th European Conference on Developmental Psychology, Bergen, Norway.
- **Cochet, H.**, & Vauclair, J. (2011, June). *Hand preference for gestural communication and the question of language origins.* Oral presentation at the 23rd annual Conference of the Human Behavior and Evolution Society, Montpellier, France.
- **Cochet, H.** (2010, novembre). *Asymétrie des gestes communicatifs et développement du langage*. Laboratoire de psychologie du développement et des troubles du langage, Faculté de Psychologie et des Sciences de l'Education, Université de Genève, Genève, Suisse.
- **Cochet, H.**, & Vauclair, J. (2010, July). *Patterns of handedness for communicative gestures in human children.* Graphic presentation presented at the 4th Conference of the International Society for Gesture Studies, Frankfurt/Oder, Germany.
- **Cochet, H.**, & Vauclair, J. (2010, April). *Gestural communication in human children: Ontogenetic perspective in favour of the gestural hypothesis of language origin.* Graphic presentation presented at the Evolang 8th Conference, Utrecht, Netherlands.
- **Cochet, H.** (2009, juin). *Forme, fonction et latéralité des gestes spontanés de pointage produits par de jeunes enfants.* Communication affichée au Congrès annuel de la Société Française de Psychologie, Toulouse, France.

- **Cochet, H.**, & Vauclair, J. (2009, July). *Relationship between language development and laterality for pointing gestures in toddlers.* Graphic presentation presented at the international conference Multimod, Toulouse, France.

RESEARCH / WORK EXPERIENCE

- **2008 – 2011.** Tutorials in Developmental Psychology, 168h (University of Provence, B.A. Psychology students).
- **2010.** Tutorials in Neurobiology, 24h (University of Provence, B.A. Psychology students).
- **July – August 2006**. Internship with Bernard Thierry at Strasbourg Primate Center, France. Assistance in food exchange experiments with humans in capuchin monkeys (*Cebus apella*).
- **June 2006**. Internship with Vincent Bretagnolle at the Chizé Center for Biological Studies, France. Assistance in rearing of Montagu's harriers (*Circus pygargus*) for CNRS conservation plan.